An analysis of the perceived causes leading to task-failure in resistance-exercises

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Background: While reaching task-failure in resistance-exercises is a topic that attracts scientific and applied interest, the underlying reasons leading to task-failure remain underexplored. Here, we examined the reasons subjects attribute to task-failure as they performed resistance-exercises using different loads. *Methods:* First, twenty-two resistance-trained subjects (11-females) completed one Repetition-Maximum (RM) tests in the barbell squat and bench-press. In the next two sessions, subjects performed two sets to task-failure in both exercises, using either 70% or 83% of 1RM. Immediately after set-completion, subjects verbally reported the reasons they perceived to cause task-failure. Their answers were recorded, transcribed, and thematically analyzed. The differences between the frequencies of the identified categories were then tested using a mixed logistic regression model. *Results:* The most commonly reported reason was muscle fatigue (54%, $p<.001$), mostly of the target muscles involved in each exercise. However, remote muscles involved to a lesser extent in each exercise were also reported. Approximately half of the remaining reasons included general fatigue (26%), pain (12%), cardiovascular strain (11%), and negative affect (10%), with the latter reported more often in the squat ($p=.022$). *Conclusions:* In contrast to our expectations, task-failure was perceived to be caused by a range of limiting factors other than fatigue of the target muscles. It now remains to be established whether different perceived limiting factors of resistance-exercises lead to different adaptations, such as muscular strength and hypertrophy.

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Abstract

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Conclusions: In contrast to our expectations, task-failure was perceived to be caused by a range of limiting factors other than fatigue of the target muscles. It now remains to be established whether different perceived limiting factors of resistance-exercises lead to different adaptations, such as muscular strength and hypertrophy.

Keywords: Resistance-exercise, perception, task-failure, repetition-maximum

Introduction

Whether one should reach task-failure in resistance-exercises is a question that attracts scientific and applied interest (Nóbrega & Libardi, 2016; Davies et al., 2016; Sampson & Groeller, 2016). Here we refer to task-failure as either momentary-failure (MF), the point in which an attempted repetition cannot be completed with proper form, or repetition maximum (RM), the final repetition one can complete prior to reaching MF (Steele et al., 2017). It has been established that reaching or approaching task-failure is important for hypertrophy and strength development (Davies et al., 2016; Morton et al., 2016). Yet, to date, little is known about the reasons underpinning task-failure. Although it can be expected that the inability to generate the required force with the target muscles is the main reason for task-failure, perception of fatigue, negative feelings, cardiovascular strain and pain can also be at play. Reaching task-failure due to one or more of the aforementioned factors could lead to different adaptations. For example, reaching task-failure because one cannot generate enough force with the target muscles is possibly more effective for hypertrophy purposes compared to reaching task-failure because of cardiovascular strain, or pain in body parts other than the target muscle groups. While investigating the underlying physiological causes of task-failure is a challenging task, examining the subjective aspects believed to cause task-failure is attainable and can shed light on this important issue.

One effective way to study subjective experiences during resistance training is with single-item scales (Buckley & Borg, 2011; Helms et al., 2016; Hackett et al., 2017). For example, rating of perceived effort (RPE) scales can assist quantifying how much effort one is investing during, or after set completion, and allow for comparisons between different exercises, loads, and body parts involved in the exercise (Buckley & Borg, 2011; Hackett et al., 2017). Interestingly, when sets are taken to task-failure, perceived effort is not always rated as maximal, indicating that

effort is not the limiting factor in such cases (Pritchett et al., 2009). These results led investigators to examine if other constructs can be the reason people terminate a set (Steele et al., 2016). A number of studies found that perception of discomfort, rather than RPE, was maximal at the point of set-termination, suggesting that discomfort can be a limiting factor (Fisher & Steele, 2017; Stuart et al., 2018). Other popular scales gauge how many repetitions trainees estimate they can complete before reaching task-failure (Helms et al., 2016; Hackett et al., 2017). To illustrate, a rating of two indicates that only two more repetitions are left before reaching task-failure (Hackett et al., 2017). These scales are similar to RPE scales although developed solely for resistance training (Helms et al., 2016; Hackett et al., 2017). While single-item scales are practically useful and lead to theoretical insights (Halperin & Emanuel, 2019), they lack the resolution required to pinpoint the reasons why task-failure occurs. This is because they depend on a single question, which revolves around a single construct, to which people can only provide a single answer. Hence, other strategies of investigations are warranted.

One way to investigate the causes leading to task-failure is to ask subjects why they terminated a set and allow them to answer in an unrestrictive manner. This measurement strategy can expand our understanding of set termination that goes beyond the insightful, yet limited knowledge, gathered via single-item scales. Such knowledge could lead to new research avenues. The limiting factors may vary as a function of the exercise completed and the loads lifted. Hence, in this study we instructed resistance-trained subjects to reach task-failure in the squat and bench-press exercises under two load conditions (70% and 83% of 1RM), and within 20-40 seconds after set completion, we asked them what was the limiting factor in the set, and why they could not perform another repetition. Subjects' answers were recorded, transcribed and analyzed.

Materials & Methods

Study design

The study consisted of three testing days with three to eight days between sessions. The first day consisted of 1RM tests for the barbell back-squat followed by the barbell bench-press, and an explanation of the experimental procedure. In the following two sessions, subjects performed two sets with the barbell squat followed by two sets with the barbell bench-press to task-failure, in a randomized, counterbalanced order. While subjects were asked to reach MF in all sets, they were informed that they can terminate the set at RM. Hence, across days, task-failure was determined either by 1) inability to complete a repetition (MF), 2) subjects' decision to terminate the set based on their assumption that they can't complete another repetition (RM), or 3) technical failure determined by the experimenter. Subjects lifted either 70%1RM in one day or 83%1RM in the other day in both exercises. The 70% and 83% loads were selected as they are within the recommended range for development of hypertrophy and strength for trainees with a range of training backgrounds (Kraemer & Ratamess, 2004). Also, lifting these two loads to task-failure can be expected to lead to considerable differences in the number of repetitions people are able to complete. This study employed the same protocol as in (Emanuel, Smukas & Halperin, 2020), yet tested different dependent variables which were previously unattended.

In the two experimental sessions, after each set, the researcher noted if the set was terminated due to RM or MF. The researcher then asked the subjects what were the limiting factors in the set, and why they could not perform another repetition. Subjects answered this question as they saw fit, without any restrictions. All answers were recorded with a tie-on microphone attached to the subjects' shirt and were later transcribed and analyzed. Subjects were asked to refrain from an intense training session 24 hours prior to testing days and to avoid a heavy meal and caffeinated drinks or supplements at least three hours before testing sessions. All sessions were

performed in the same facilities and ran by the same experimenter at approximately the same hour of the day ($\pm$ 2 hours).

Subjects

Twenty-two resistance trained subjects volunteered to participate in this study (Table 1). Inclusion criteria consisted of healthy subjects between the ages of 18 and 45; a bench-press 1RM of at least 1.2 and 0.7 times the bodyweight for men and women, respectively; and at least 1.2, and 1 times the bodyweight in the squat. Subjects had to have at least one year of resistance training experience, and specifically at performing the free weight squat and bench-press. Additionally, subjects had to have some familiarity with taking sets to task-failure. Each subject signed an informed consent on the first day. This study was approved by the Tel-Aviv University institutional review 2019-0325.

Procedures

1RM tests (day 1). Subjects were first weighted, indicated their height, age and experience in strength training. They were then briefed on the study's aims. All subjects then performed a squat to a height adjustable box which was set to achieve a knee angle of 115-120 degrees (mean knee angle= 118, SD= 5.93). Subjects had to lightly touch the box with their gluteus prior to initiating the concentric phase. During the bench-press subjects' preferred grip and body position were recorded and maintained throughout the study. In each repetition the bar must have lightly touched subjects' chest prior to the concentric phase. Subjects then performed a structured warmup protocol consisting of calisthenics and dynamic warmup followed by an individualized five-minutes warmup. This warmup protocol was identical in all sessions. Subjects then performed the barbell squat and bench-press 1RM protocol which consisted of a similar

progression towards an estimated 1RM indicated by the subjects: 10,5,3,3,2,1 repetitions with empty bar, 40%, 60%, 70%, 80% and 90% of approximated 1RM, respectively. The increase in weight to the true 1RM was decided by the subjects and experimenter with 3-5 minutes of rest between 1RM attempts.

Experimental sessions (day 2-3). Following the general warmup protocol (see above), subjects performed the following specific warmup for the squat and again for the bench-press following the sets to task-failure with the squat: 10,5,3,1 repetitions with an empty bar with 40%, 55%, 70% of 1RM in the lighter day, or added another set of one repetition with 83% of 1RM in the heavier day. Following the last warmup set, subjects rested for two minutes and performed two sets to task-failure in the squat followed by the bench press with either 70% or 83% of 1RM. Six minutes of rest were provided between sets and exercises. Subjects were instructed to perform the concentric portion of the lift as fast as possible, while maintaining a controlled ~2 seconds descend. Within 20-40 seconds after set completion, subjects were asked what were the limiting factors in the set, and why they could not perform another repetition.

(Table 1 near here)

Data preparation

We followed a similar approach used by Halperin et al. (2016). Initially, general categories that were expected to account for set termination were extensively discussed by the authors. These categories included general and specific fatigue, pain, negative affect, and cardiovascular strain (see below). Then, the first and last authors read all of the transcribed statements and examined if the agreed upon categories were present, needed to be refined, and whether other ones were noticed. In case that newer categories were identified, a discussion took place in order to decide

154 if they should be included. Once the categories were agreed upon, the first and last authors
155 picked at random a few statements and rated them simultaneously to confirm comparable ratings.
156 Thereafter, the raters rated all statements individually. Each statement was rated once in a binary
157 manner in each category. The raters then compared their overall ratings. Cases of mismatches
158 were thoroughly discussed between the two raters until reaching an agreement. Note that the
159 same statement could have been rated in more than one category. The final categories included
160 the following:

161 *General fatigue*: statements with terms such as fatigue, tired, lack of energy, power or strength,
162 all in relation to the whole body, or described as a general perception.

163 *Specific fatigue:* as described above, but the perceptions had to be attributed to muscles or a
164 location in the body.

165 *Cardiovascular strain:* statements indicating that breathlessness or heartrate were the reasons for
166 set-termination.

167 *Pain:* statements indicating a painful experience, including terms such as pain, hurt, pinch, and
168 burning.

169 *Negative affect:* statements indicating an overall bad experience including terms such as
170 annoyance, bad, terrible, and not fun. Table 2 provides examples of the statements provided in
171 each of the five categories across exercises, loads, RM/MF and gender, and their rating in each
172 category. Since subjects provided the answers in Hebrew, the first author, who is fluent in both
173 Hebrew and English, translated the statements into English.

174 (Table 2 near here)

Data analysis

We tested for differences between the frequencies of the categories across loads and exercises in a mixed logistic regression model (the cardiovascular category was coded as 0). We next tested for differences in the frequency of each category between conditions and exercises via five separate mixed logistic regression models, one for each category (the frequency in a given category was the dependent variable while condition and exercise were the independent variables). In all mixed regression models, random effects and interactions were added based on improvement in model fit, as indicated by the deviance statistic. In addition, the specific body parts mentioned, if any, under the muscle fatigue and pain categories were mapped (e.g., upper-body, quadriceps), counted, and reported. Significance was set at $p < .05$. Statistical analyses were carried out with R (version 3.6.0) using the lattice package.

Results

Overall, 158 statements from terminated sets were recorded with only 37 sets terminated due to MF and the rest due to RM. We had ten missing observations in the 83%1RM bench-press condition; four due to drop-outs and six due to technical difficulties. We had four more missing observations across the other conditions and exercises due to technical difficulties.

Out of the 158 statements, muscle fatigue was found to be the most frequent category accounting for 53.8% of the terminated sets (b=2.20, SE=.296, z=7.42, p<.001). The second most frequent category was general fatigue accounting for 25.9% of the terminated sets (b=1.00, SE=.309, z=3.24, p=.001), followed by pain (12%), cardiovascular (11.4%) and negative affect (10.1%). No significant differences were found between the frequency of either pain (b=.06, SE=.350,

196 z=.175, p=.861) or negative affect (b=-.131, SE= .363, z=-.363, p=.716) and the cardiovascular
197 category (See Figure 1).

198 Negative affect was found to be a more frequent reason for set-termination in the squats
199 compared to bench-presses (b=1.52, SE=.669, z=2.27, p=.022), muscle fatigue was found to
200 marginally differ between loads (b=.047, SE=.027, z=1.72, p=.084), and cardiovascular strain
201 was found to marginally differ between loads (b=-.111, SE=.058, z= -1.91, p=.056) and exercises
202 (b=1.19, SE=.704, z=1.69, p=.090) (see Figure 1). No other significant differences were found in
203 pain and general fatigue between exercises and loads (all p_s >.11).

204 (Figure 1 near here)

205 Discussion

206 Here we examined what limiting factors were perceived to lead to task-failure in the squat and
207 bench-press exercises using 70% and 83% of 1RM, among resistance-trained subjects. Subjects
208 were required to state what were the limiting factors of each set within 20-40 seconds after
209 reaching task-failure. Of the five categories used to map subjects' responses, specific muscle
210 fatigue was the most frequently reported. Within the muscle fatigue category, the target muscles
211 (i.e., prime movers) in each exercise were specified in most, but not all of the responses. The
212 remaining responses were categorized as general fatigue, pain, negative affect and cardiovascular
213 strain. No differences in the distribution of categories were identified between males and
214 females.

215 As can be expected, most sets were perceived to be terminated because of muscle fatigue
216 attributed to target muscle groups (i.e., lower body for squats and upper body for bench-press).
217 However, within this category, certain variability was noted. In the squat, 27% (13/47) of the

218 statements within the muscle fatigue category were attributed to the upper body and lower back,
219 indicating that in these cases, task-failure was not perceived to be due to the target muscles.
220 Moreover, different muscles within the legs were mentioned, including the gluteus, quadriceps
221 and hamstring, indicating that limiting factors within the target muscle groups can vary between
222 individuals. In the bench-press, some variability was also noted within the target muscle groups,
223 with the chest muscles being reported the most, followed by the arms (presumed to be triceps)
224 and then the shoulders. It is interesting to consider whether variations in the perceived muscle
225 group being the limiting factor in a given exercise can lead to different adaptations, such as
226 strength and hypertrophy. Alternatively, whether suboptimal adaptations may occur when
227 unrelated muscles are considered to be the limiting factor in exercise-performance.

228 General fatigue was also frequently attributed to set termination across exercise and loads. This
229 could indicate that multi-joint exercises involving large muscle groups produce a global and
230 unspecified feeling of fatigue strong enough to lead to set-termination. While pain, negative
231 affect, and cardiovascular strain were mentioned fewer times compared to specific and general
232 fatigue, some interesting patterns emerged. Mainly, the results indicate that more sets in the
233 squats were terminated due to pain and negative affect compared to bench-presses, and that in
234 the 70%1RM squat condition more sets were terminated due to cardiovascular strain. Some of
235 these findings are aligned with other studies. For example, lower body exercises have shown to
236 cause greater degree of negative affect compared to upper body exercises (Portugal et al., 2015).
237 These findings suggest that squats may be limited by a wider range of factors, compared to the
238 bench-press.

239 This study has several methodological aspects worthy of discussion. First, asking subjects to
240 answer the question concerning set termination within ~30 seconds can be viewed both as a

strength and a limitation. Asking the question in proximity to set termination was expected to lead to a more accurate answer, but given the physically challenging nature of the task, subjects may have provided less details. Similarly, subjects were allowed to answer the question without any restrictions, but this may have caused important information to be lost that a more structured questioning procedures might have captured. Second, no physiological outcome, such as heartrate, was measured and correlated with participant's statements. In view of the aforementioned points, future studies could also include structured or semi-structured interviews about the limiting factors at different time points after set-termination and also include various physiological measures.

Conclusions

We observed that set-termination was mostly perceived by subjects to be a result of muscle fatigue in the target muscles, followed by a general feeling of fatigue, negative affect, pain and cardiovascular causes. These reasons were found to vary between exercises and loads. The results of this study show that there are a variety of perceived reasons for set termination, which might affect exercise-adaptations, and warrant further investigation.

As studies continue to investigate how many repetitions one completes relative to task-failure, it may be of added value to examine what are the limiting factors leading to set-termination. This is because different limiting factors within sets could lead to different acute and long-term adaptations that are alighted to a lesser or greater extent with the sought-after outcomes. Investigating limiting factors can be done by directly measuring the possible physiological pathways leading to set-termination. Such studies require complex designs and equipment. An alternative is to study the subjective experiences accounting for set-termination, as was done in

the present study, and to our knowledge, for the first time. The present investigation may indicate that relying on task-failure as a gold-standard for load and repetition prescription may fail to capture a variety of limiting factors other than fatigue of the target muscles. Thus, it could be that in addition to prescribing one to reach task-failure, or proximity to task-failure, monitoring other aspects of set-termination may prove beneficial. For example, loads can be modified in cases that cardiovascular strain or negative affect are reported at set-termination, and exercise technique can be modified in cases that target muscles are not perceived to be a limiting factor. However, it is required to first establish what type of relationships, if any, exist between perception of the limiting factors and actual adaptations.

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Figure captions

Figure 1. The distribution of each category by exercises and loads. Panels A-E depict the muscle fatigue, general fatigue, pain, cardiovascular, and negative affect categories, respectively. The y-axis represents the percent of each category, calculated as the number of ratings, divided by the number of sets in each exercise and load.

Figure 1

The distribution of each category by exercises and loads

Figure 1. Panels A-E depict the muscle fatigue, general fatigue, pain, cardiovascular, and negative affect categories, respectively. The y-axis represents the percent of each category, calculated as the number of ratings, divided by the number of sets in each exercise and load.

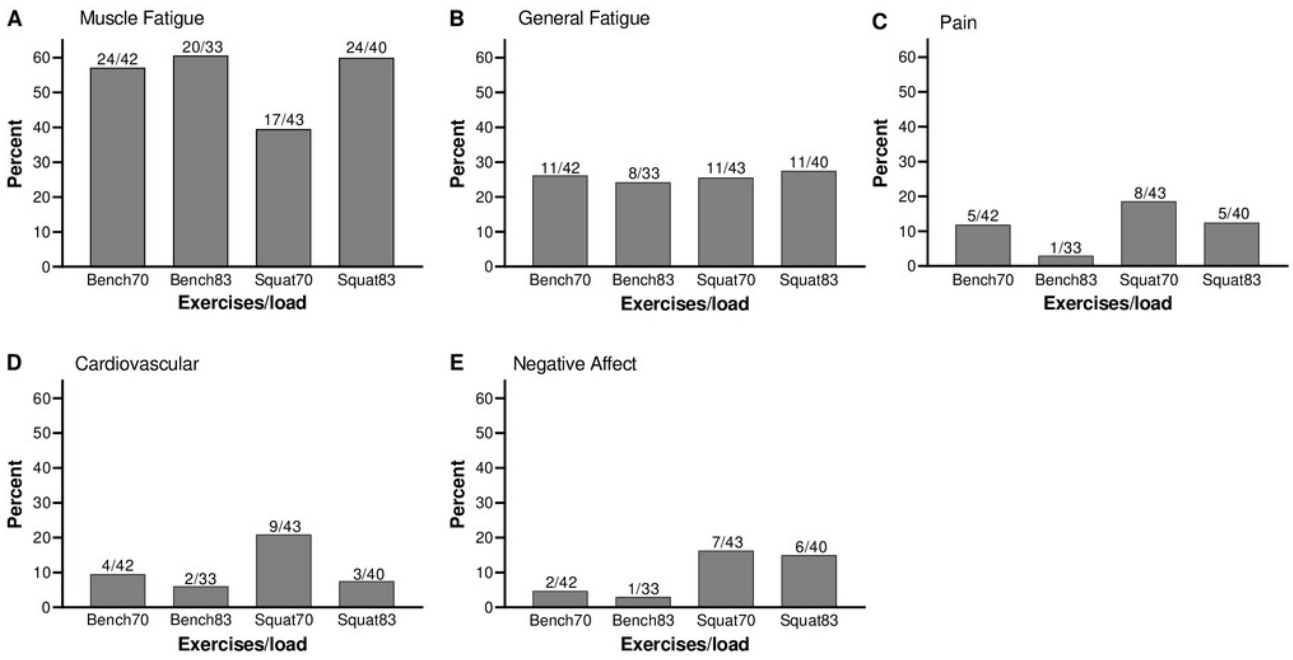

Table 1(on next page)

Table 1. General Demographics

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	Females (n=11) Mean±SD (Range)	Males (n=11) Mean±SD (Range)
Age	29±4 (23-38)	30±4 (22-37)
Height (cm)	167±6 (156-175)	175±6 (167-185)
Weight (kg)	62±7 (52-75)	78±4 (71.7-85.7)
Experience in RT (yrs)	3±2 (1-8)	9±4 (3-18)
Mean workouts per week	3±1 (1-5)	3.5±.8 (2-5)
1RM barbell bench press (kg)	45±9 (31-60)	100±14 (75-130)
1RM/ Bodyweight bench press	0.71±0.12 (0.53-0.87)	1.29±0.22 (1-1.7)
1RM barbell squat (kg)	74±14 (55-100)	126±20 (100-155)
1RM/ Bodyweight squat	1.19±0.24 (0.81-1.50)	1.6±0.27 (1.2-1.6)

Table 2(on next page)

Table 2. Example of statements

Table 2. Examples of answers provided to the question posed after set-completion: "What were the limiting factors of the set and why couldn't you perform another repetition?". The ratings of each answer are divided by category, exercise, load, and set endpoint condition (* indicates MF).

Load	Answers	Muscle Fatigue	General Fatigue	Affect	Cardio	Pain
Squats						
70%	A general feeling of exhaustion.		**x**			
70%*	My quadriceps and hamstring muscles.	**x**				
70%	My lower back and my left quadriceps but also an unpleasant feeling in my body.	**x**		**x**		
70%	I didn't reach failure, I just had enough.			**x**		
83%	I couldn't push with my legs any more, I feel fatigued.	**x**	**x**			
83%	I felt stuck and a pressure in my lower back muscles.		**x**			**x**
83%	Mostly because of cardiovascular reasons but my legs were also hurting and the bar felt heavy on my shoulders.				**x**	**x**
83%	A general lousy feeling. I just wanted to get it over with.			**x**		
83%	A general feeling of fatigue of the whole system rather than just the muscles in my legs.		**x**			
83%	I run out of power and knew I wouldn't be able to complete another repetition.		**x**			
Bench-press						
70%	The limiting factor was fatigue in my left shoulder muscles.	**x**				
70%*	I never felt my chest muscles fatigued like this before.	**x**				
70%*	I can't really explain it, I felt that I just ran out of strength.		**x**			
70%	My heartrate. I felt it from the very first repetition.				**x**	
83%*	Without a doubt it was my chest muscles. Not my triceps as I expected.	**x**				
83%	The limiting factor was mostly psychological. As if I gave up on the next repetition.			**x**		
83%	Pain in my left wrist.					**x**
83%	I ran out of strength in my chest muscles.	**x**				
83%*	A combination of different reasons, including lower back pain, fatigue in my shoulder and arm muscles, and a feeling of breathlessness.	**x**			**x**	**x**
83%	The limiting factor was my ability to produce strength with my upper body.	**x**				

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