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ORIGINAL INVESTIGATION

Evidence That Rating of Perceived Exertion Growth During Fatiguing Tasks is Scalar and Independent of Exercise Mode

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Introduction: The relationship between the percentage of a fatiguing ambulatory task completed and rating of perceived exertion (RPE) appears to be linear and scalar, with a relatively narrow "window." Recent evidence has suggested that a similar relationship may exist for muscularly demanding tasks. ***Methods:*** To determine whether muscularly demanding tasks fit within this "ambulatory window," we tested resistance-trained athletes performing bench press and leg press with different loadings predicted to allow 5, 10, 20, and 30 repetitions and measured RPE (category ratio scale) at the end of the concentric action for each repetition. ***Results:*** There was a regular, and strongly linear, pattern of growth of RPE for both bench press ($r = .89$) and leg press ($r = .90$) during the tasks that allowed 5.2 (1.2), 11.6 (1.9), 22.7 (2.0), and 30.8 (3.2) repetitions for bench press and 5.5 (1.5), 11.4 (1.6), 20.2 (3.0), and 32.4 (4.2) repetitions for leg press, respectively. ***Conclusions:*** The path of the RPE growth versus percentage task fit within the window evident for ambulatory tasks. The results suggest that the RPE versus percentage task completed relationship is scalar, relatively linear, and apparently independent of exercise mode.

Keywords: fatigue, resistance exercise, cycling, running

The rating of perceived exertion (RPE)[1] is a widely accepted method for measuring intensity during exercise. During aerobic training, methods such as heart rate (HR), oxygen consumption (VO_2), and blood lactate have traditionally been used to measure intensity. All are well correlated with RPE.[2–4] Conventional objective aerobic training markers depend on the availability of data from a maximal exercise test to define VO_2max and HR_{max} as anchor points. In resistance training, the one repetition max (1RM) is the gold standard for prescribing exercise since HR, VO_2, and blood lactate are not effective ways of measuring intensity.[5,6] These studies have shown that RPE is well-related to %1RM. Similar to aerobic exercise, which requires an anchoring maximal exercise test, the 1RM strategy is not a practically effective way to define the exercise prescription as it is rarely used with untrained individuals and would depend on measuring 1RM for a very large number of exercises. A modification of the RPE approach, the session RPE (sRPE) has been shown to be related to the relative intensity of training during entire aerobic exercise and resistance training sessions and competitive sports.[7,8]

Impellizzeri et al[9] suggested that the internal training load is mostly associated with improved performance. Optimizing the internal training load requires manipulation of the training load (relative intensity × volume/time). Accordingly, more fit individuals must perform a larger external training load to achieve the same internal training load. To measure the internal load, researchers have used physiological responses (typically $\%HR_{max}$ or $\%HR_{reserve}$, $\%VO_2$max, or %1RM). The RPE[2] represents the momentary perceived intensity while the sRPE represents the whole training session.[3,7,8] There are several scales for RPE[1] including the classical (6–20) scale, the Category Ratio (0–10) scale, and the Omni scale.[10] Although producing different absolute values for the computed training load (sRPE × duration), the between scale behavior of different versions of the RPE scales have been shown to be well-correlated markers of relative intensity, hence the internal training load.[11,12]

The RPE represents the overall sense of exertion either at a certain moment[2,13] during sustained exercise,[14–16] or after an entire training session.[3,7,8] During incremental exercise, RPE typically increases in proportion to the relative muscular power output.[2,4] During aerobic exercise, RPE typically increases in a more or less linear manner, which is scaled to the percent of a task completed.[14–19] Typically, RPE will also increase across elements of an interval training session[20] and will increase progressively at the same workload if heavy training is sustained for several days.[21]

Ulmer[22] proposed the concept of teloanticipation, or the growth of RPE in relation to the relative percent of a task completed. This demonstrated the capacity of feedback relative to the intensity × duration of exercise that allowed the motor control system to perform subconscious internal calculations, accounting for the progressive extent of homeostatic disturbances based on the anticipated duration of a planned task.[22] This bidirectional motor signaling between the motor center and the muscle include information not only for mechanical aspects of motion but also for communicating the magnitude of homeostatic disturbance, designed to ensure that the intensity of the metabolic rate is analogous to the somatosensory feedback.[23] From this beginning point, Tucker proposed that there are numerous signals sent to the brain.[24] The afferent signals combined with a preexercise template[17,25] and sensory feedback responses (represented by RPE) can then be used to regulate the level of exertion. Therefore, the subconscious brain takes into account anticipated "finishing points" and receives afferent feedback from physiological systems to develop and then modify pacing strategy. The interaction of this pacing strategy and afferent feedback will allow the exerciser to regulate effort in a way

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designed to reach maximal RPE near the finish while ensuring that unacceptable homeostatic disturbances do not occur.[24] This process has been discussed under the general rubric of pacing.[26]

The most important factors that impact pacing are temperature, oxygen availability, substrate availability metabolite accumulation, and duration of the task.[4,14,15,17–19,26–29] Arguably the most important feedback to pacing is distance or duration feedback.[22,30–35] This is the idea that the endpoint of exercise must be known (or anticipated) prior to the start of an exercise bout to serve as an "anchor point." From here, the body can use this point to elicit the correct physiological response needed to complete that exercise. If given incorrect information, performance can be mismatched, eventually resulting in incorrect physiological response based the expectations that were given or assumed.[30,36] Momentary disruptions in the pattern of normally paced power output, such as by a "break-away effort" can disrupt the power output–RPE–relative distance relationship.[31]

A variety of studies, mostly using aerobic exercise to fatigue, or time-trial exercise, have suggested a "window" of RPE growth relative to the percent of task completed[14–19,24–26,31,35] (Figure 1). This "window" may be disrupted by deception regarding percent of task completed[30,31,36] or mid-task increases in exercise intensity,[31] but normally follows a characteristic pattern of growth.

These studies demonstrate the scalar pattern of RPE growth during self-paced aerobic exercise. There is less information to show if the pattern of growth of RPE is scalar, and acts during exercise requiring high muscle forces, such as resistance training. Recently, Emanuel[5] has shown a similar pattern of growth of RPE during successive repetitions within "sets" of resistance training (Figure 2). This suggests that there may be a generalizable pattern of growth of RPE in relation to the proportion of a task completed. This finding is a reasonable prediction of the teleoanticipation concept of Ulmer[22] that deserves to be further tested.

The RPE has been shown to be a valid method to quantify intensity of resistance training after the completion of a set,[37–39] but there is little evidence to understand teloanticipation within a resistance training set using RPE. Only Emanuel et al[5] have examined the serial effects of lifting lighter and heavier loads on the pattern of growth of RPE. Emanuel found that an increase in 1RPE unit was associated with 11% shift toward task completion. When plotted onto the "window" of aerobic exercise percent task completion versus RPE, during resistance exercise RPE grew linearly with percent of maximal repetitions just as RPE grew with percent distance or percent time remaining during aerobic exercise (Figure 2).

These findings suggest the presence of a generalizable relationship between %task completion and RPE. If this were indeed the case, it would improve our understanding of the applicability of Ulmer's[22] teleoanticipation concept. Accordingly, it is hypothesized that regardless of the number of repetitions being performed, RPE will increase in a scalar manner relative to percent of maximal repetitions completed, similar to the scalar properties that RPE has for aerobic exercises with %time or %distance completed. Thus, the aim of the study is to compare the growth of percent task completed versus RPE growth during resistance training in relation to a "window" of this relationship based on published studies.

Methods

The subjects were 21 well-trained males (from American football, basketball, and track and tennis) using resistance training to supplement their sport-specific training who had performed systematic resistance training, at least twice a week, for at least 6 months. Subject characteristics are presented in Table 1.

Procedures

Following approval from the University of Wisconsin-La Crosse Institutional Review Board for the Protection of Human Subjects (protocol #45CFR46.46 2010, approved October 6, 2010), the subjects proved written informed consent before participating. All subjects initially performed a 1RM on the bench press and the leg press exercises. Since the subjects were experienced in weightlifting, individuals estimated what they thought was their 1RM for each exercise to guide the warm-up and progression rate.

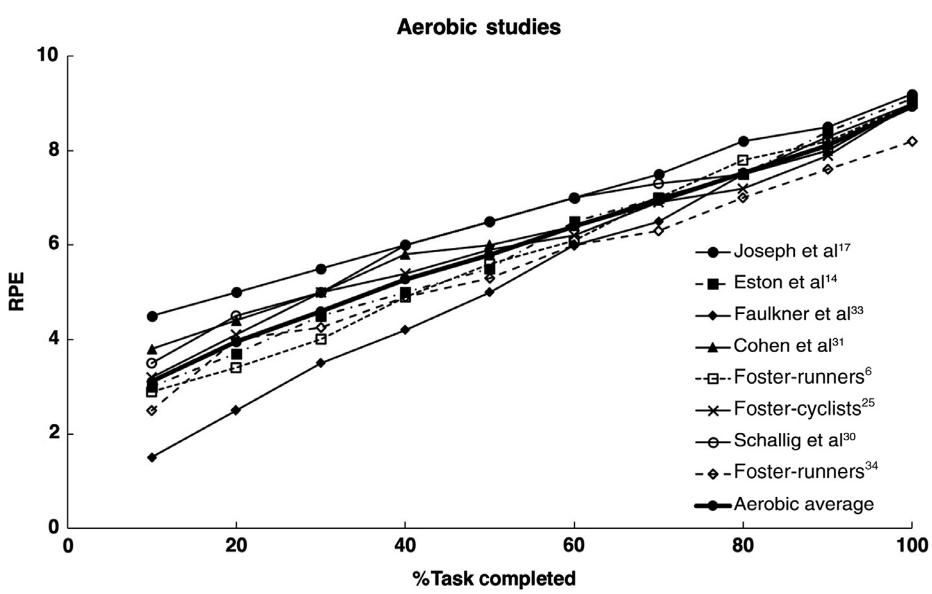

Figure 1 — Aerobic studies highlighting the "window" or RPE growth relative to the percentage task completed. For example, a rating of 5 (hard) is observed around 30% to 50% of task completion. Data contributions are listed from the references by number. RPE indicates rating of perceived exertion.

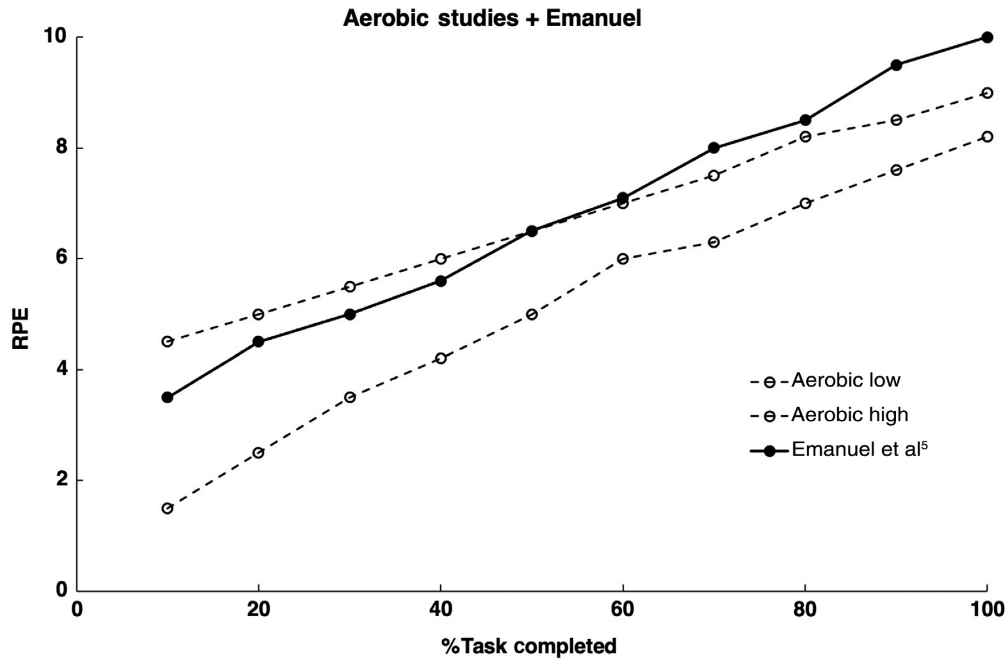

Figure 2 — The window of percentage task completed versus RPE data in aerobic exercise together with recently collected data (Emanuel et al[5]) that highlight the common "window" of RPE growth relative to the percentage task completed. RPE indicates rating of perceived exertion.

Table 1 Descriptive Characteristics of the Subjects (N = 21)

Age (y)	22.1 (2.3)
Height (cm)	181.7 (8.1)
Body mass (kg)	86.2 (12.1)
1RM bench press (kg)	109.9 (19.5)
1RM leg press (kg)	198.7 (22.7)

Abbreviation: RM, repetition maximum. Note: Data are represented as mean (SD).

Two warm-up sets were completed consisting of 8 reps at 50% of their estimated 1RM and 4 reps at 70% or their estimated 1RM. Their first attempt to reach their 1RM was at 90% of their estimated 1RM. Following this attempt, the weight was adjusted to find their 1RM weight within the next 3 attempts. Two minutes of rest was given between the warm-up sets and between each additional attempt to reach their 1RM. Subjects completed the bench press or leg press in random order and had 5 minutes of rest between the 2 exercises. After completing their 1RM on each exercise, the subjects rested for 5 minutes and then practiced using the Borg Category Ratio RPE (0–10) scale at 65% of their 1RM for 12 repetitions. Subjects reported their RPE at the completion of the concentric phase of each repetition.

Following their maximal tests and practice session, the subjects completed 4 randomly ordered trials, with a weight predicted to allow 5RM, 10RM, 20RM, and 30RM for the leg press and bench press, with 72 hours between each trial. Subjects were given two warm-up sets with 2 minutes of rest in-between and 5 minutes rest between the 2 exercises.

Each subject was told to exercise until failure and to keep a constant lifting pace. Leg press weight was, respectively, set at 90%, 78%, 58%, and 43% of 1RM and bench press weight was, respectively, set at 87%, 75%, 55%, and 40% of their 1RM, according to Baechle[40] so the subject had a reasonable basis on

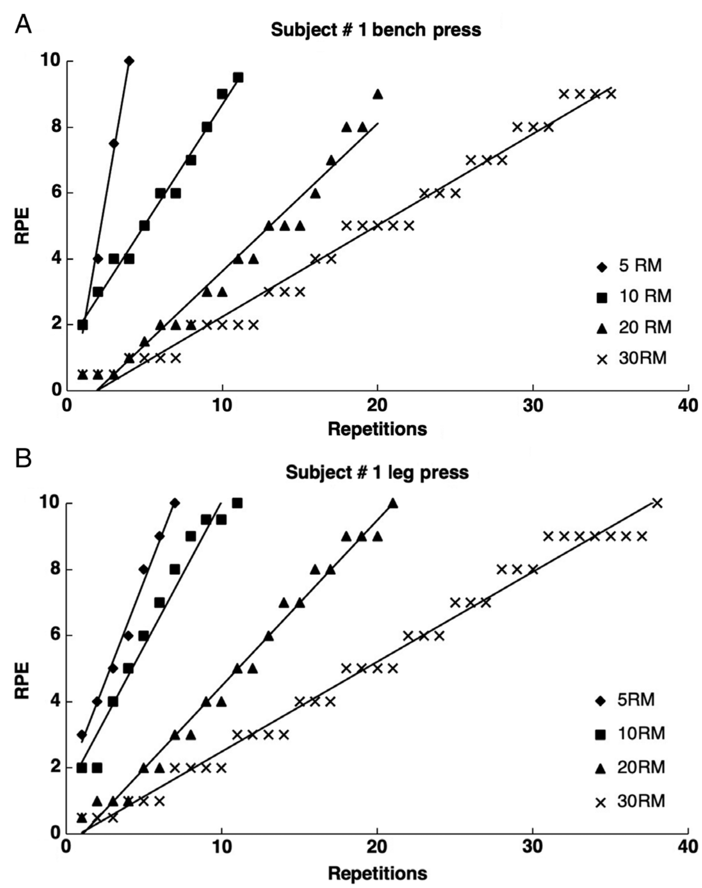

Figure 3 — Representative subject to highlight the pattern of RPE growth relative to the percentage of the task completed (A: bench press, B: leg press), in this case repetitions completed in a 5RM, 10RM, 20RM, and 30RM. RM indicates repetition maximum; RPE, rating of perceived exertion.

which to anticipate the number of repetitions they could perform. Ideally, subjects reached predicted number of maximal repetitions. However, they exercised to failure and the measured number of repetitions and RPE at the completion of each repetition was recorded as their score.

Statistical Analysis

A regression line was computed for each subject's trials to show the relationship between the number of repetitions and RPE score. The data were normalized to their maximum number of repetitions to show their trials on a comparable scale. Next, the 4 trials were combined to create one overall regression line of RPE growth in relation to percent of task completed. Figure 3 is an example of this for a representative subject.

All individual data was combined to create a group regression line in order to compare RPE growth versus the relative percent of completed repetitions for leg press, bench press, and combined lifting trials (Figure 4).

Descriptive statistics were used to characterize the subject population. Regression lines were used to analyze the correlation between the number of repetitions and RPE. The number of repetitions was then normalized to the maximal number of repetitions in each exercise in order to combine all 4 trials. This was done for each individual subject and then combined to create an overall regression line for all subjects.

Results

All 21 subjects completed all parts of the study protocol. The experimental data (mean [SD]) for each condition are presented in Table 2.

Discussion

The main finding of this study was that there appears to be a general relationship between the percent of a fatiguing task completed and

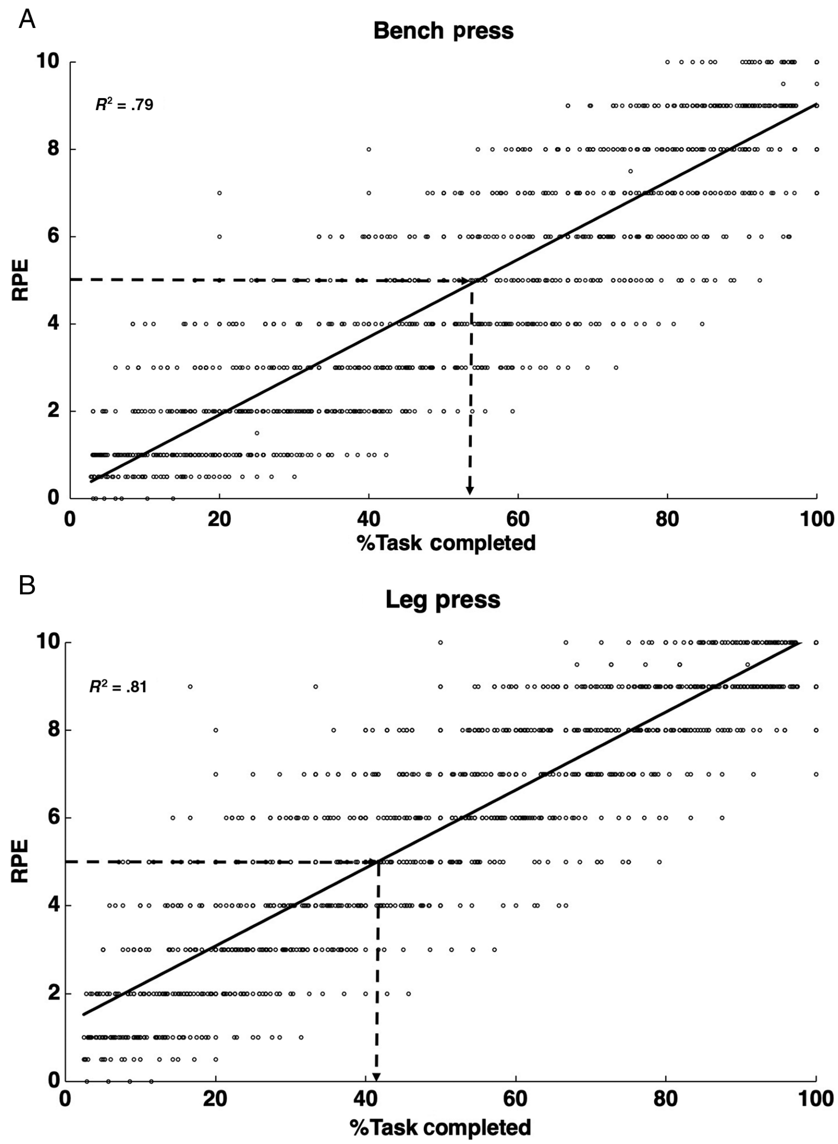

Figure 4 — Combined bench press (A) and leg press (B) data showing evidence that a person working at an RPE of 5 is at about 42% and 53% of maximal repetitions, respectively.

the growth of RPE, regardless of whether the task is reference data for treadmill walking,[14] running,[16,33,34] cycling,[17,31,33,34] or the collected data for resistance training. Within a "window" that is about ±1.0 RPE units, the expected RPE at 20%, 40%, 60%, 80%, and 100% of task completion approximates 3.5, 5, 6.5, 7.5, and 9.5, respectively (see Figure 5).

The data agree with the predictions of the teleoanticipation concept proposed by Ulmer[22], in the sense that RPE is likely to grow as one approaches the anticipated completion of a task. Unlike the data from running[16,33,34] and cycling time trials,[17,31,32] the data from treadmill walking[14] and lifting as well as the current data were collected during an exercise bout where the end was not absolutely known. However, in the present data the subjects, who were experienced with weight training, had a reasonably good preexercise estimate of how many repetitions they were likely to accomplish.[41] However, since in studies where there has been deception regarding the end of the trial[30,35,36] or mid-race changes in either effort[31] or FiO_2,[17,18] there was a very fast accommodation of RPE growth to the new conditions, it seems safe to view the data as supporting the concept that RPE is highly sensitive to the magnitude of the momentary homeostatic disturbance[41] and that the "anticipated finish" is rapidly reset.

Table 2 Experimental Data for Each Trial

Bench press				
Target reps	5	10	20	30
Actual reps completed	5.2 (1.2)	11.6 (1.9)	22.7 (2.0)	30.8 (3.2)
%1RM weight	87.7 (1.1)	76.4 (2.4)	56.8 (1.6)	47.2 (2.9)
Maximum RPE	9.2 (0.9)	9.4 (0.6)	9.4 (1.0)	9.6 (0.8)
Leg press				
Target reps	5	10	20	30
Actual reps completed	5.5 (1.5)	11.4 (1.2)	20.2 (3.0)	32.4 (4.2)
%1RM weight	91.2 (3.5)	80.7 (4.6)	64.3 (6.1)	52.4 (7.2)
Maximum RPE	9.5 (0.8)	9.9 (0.)3	9.7 (0.6)	9.7 (0.5)

Abbreviations: reps, repetitions; RM, repetitions maximum; RPE, rating of perceived exertion. Note: Data are represented as mean (SD).

The current findings fit well into the larger literature on pacing[23–26,32] and suggest that any task that is likely to be predictably fatiguing is monitored by the continual growth of the RPE. As such, the data fit into the anticipatory–fatigue–RPE model of Tucker.[24] It seems reasonable to predict that the ability to regulate the effort of resistive tasks would also show learning, as previously demonstrated for cycling[25] and be disrupted by external factors, comparable to unexpected altitude exposure in cyclists.[17–19]

From the standpoint of prescribing exercise, the growth of RPE might also serve as a strategy for deciding "how far" one should go at heavy effort to achieve a likely training effect. For example, if an RPE of 13 (on the classic 6-20 scale) is an "ideal" training intensity for normal fitness participants,[43] having someone set off at what they think is 10-km race pace but having them stop after ~3 km (when the RPE = 13 on the classic RPE scale) might be reasonable. This follows the concept of Billat et al[43] of doing interval training at 50% of the time limit at vVO_2max. Similarly, if one thinks that hard training sessions for athletes should be an RPE ~7 (on the 0–10 Category Ratio scale),[44] then training sessions of about 70% of competitive distance at competitive pace/effort might be a reasonable recommendation. Likewise, resistance training sets performed to an RPE of 7 (on the Category Ratio scale), instead of failure, might be a reasonable way to guide intensity. The value of such suggestions awaits experimental testing.[45]

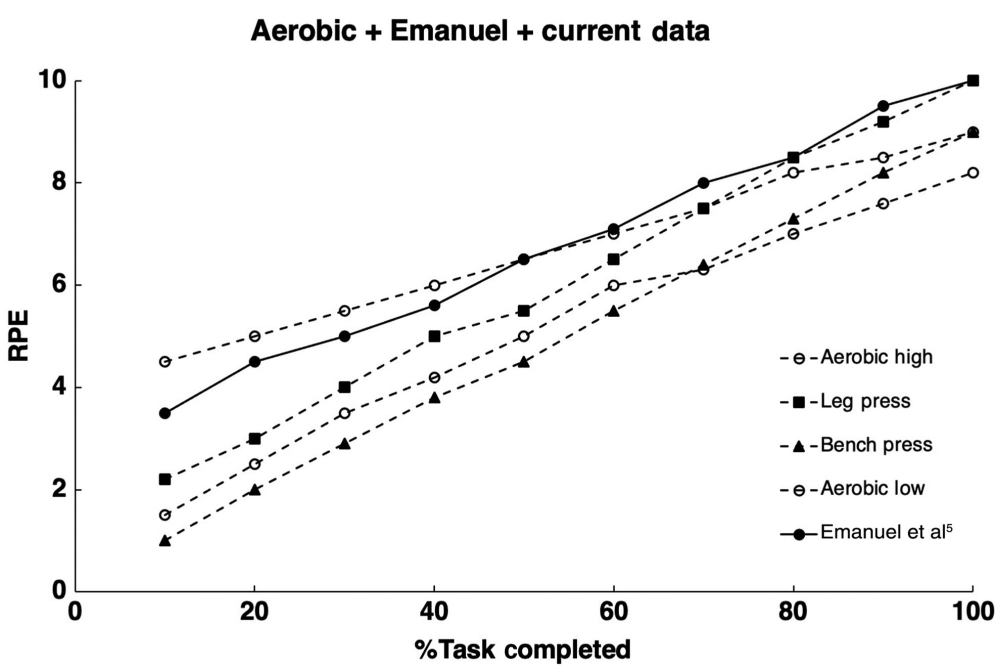

Figure 5 — Current data along with recently collected (Emanuel et al[5]) data presented against the background of aerobic studies that highlight the "window" or RPE growth relative to the percentage of the task completed. RPE indicates rating of perceived exertion.

Practical Applications

The results of the present study, viewed in context against the RPE growth versus %task completion of ambulatory tasks in the literature suggest that the response is linear, scalar, and apparently independent of exercise mode. As such, it provides a way to estimate exercise capacity (evaluation) and a way to guide training bouts (prescription). Depending on the goals of the exerciser, this generalizable response may improve our ability to optimize the efficacy, precision, and tolerability of exercise training.

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