Functional Capacity Evaluations: The Work Physiology Component for Predicting Full-time Work

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Introduction

The use of capacity evaluation test procedures has become common in the United States and other countries as a means of quantifying human tolerance for work. Capacity testing is known by several names, including *functional capacity evaluation* (FCE), *functional capacity assessment* (FCA), and *performance-based physical capacity evaluation* (PBPCE). Typical components of capacity test protocols (FCE, FCA, PBPCE) include biomechanical evaluation, strength and clinical range of motion analysis, examinee self-description of symptoms, and an analysis of physiological tolernace for work. This lesson focuses on the physiological aspect of capacity evaluation because that science has been the least well understood component of the capacity testing process.

Work physiology is one of the most important factors for predicting an individual's ability to tolerate full-time employment. Typically, commercially available software for capacity evaluation,[1] and various professional publications,[2] have cited formulas for exercise physiology predictions related to clinical diagnostic treadmill or bicycle testing or protocols related to exercise and/or fitness training using heart rate monitoring as the criteria for the determination of work fitness. However, these formulas for exercise physiology or clinical diagnostic exercise physiology are not the appropriate formulas to use to determine the longitudinal prediction of full-time work tolerance, because there are specific formulas for work physiology.

This lesson reviews the basic work physiological principles that have been neglected in capacity evaluation protocols and presents a review of exercise physiology principles that have been incorrectly applied to capacity evaluation protocols. In addition, relevant work physiological tolerances are reviewed, and simplified formulas that rehabilitation counseling professionals can consult to determine the accuracy of the capacity evaluation material they are reviewing, are presented.

Learning Objectives

In this lesson, readers will be introduced to (1) the basics of work physiology as it is applied to vocational professionals; (2) basic work physiological formulas that are used to predict full-time work in FCE reports; (3) the physiological demands of work related to heart rate response and time duration tolerance; and (4) the incorrect application of exercise physiology fitness testing predictions to capacity evaluation work analysis.

Review of Relevant Information and Research

The published articles reviewed by this author for this lesson identify a number of component tests for capacity evaluation, but none identify the science of work physiology in a definitive way.[1,3,9] King, Tuckwell, and Barrett[6] wrote a critical review of 10 well-known FCE systems, including *Physical Work Performance Evaluation* (PWPE), *Work Evaluation Systems Technology; Employment Potential Improvement Corporation* (WEST-EPIC), Blankenship FCE, Work-Ability Mark III, Isernhagen Work System, ARCON, Key Method, WorkHab, AccessAbility, and Ergos. They concluded that no scientific application regarding prediction of 8-hour work tolerance existed. The authors revealed that the tests were not standardized and lacked comprehensiveness as well as objectivity in data collection. The authors called for a new classification system in FCE testing, such that further definition of variables could be evaluated. Most importantly, the authors asked that a definitive method of data projection be established to help counselors predict if individuals being tested were capable of working an 8-hour day.

Davies[10] spoke strongly on the difference between exercise and work physiological testing pointing out that the primary barrier to progress in understanding work physiology and a broader understanding of the science was a failure to appreciate the underlying physiological principles upon which full-time work is based. He noted that attempts to consider fitness in all forms of human function led to vague generalization that ultimately violated the truth about work-tolerance physiology. His research maintained that exercise fitness testing was not a specific test of physiological prediction for prolonged work-related physical exertion and that specific procedures were needed for predicting full-time work exertion.

Other researchers, including Saunders, Beissner, and McManis[8] found that estimates of how frequently a load could be lifted were questionable when a review of a number of FCE systems was completed. These authors also determined that there was little reliability in full-time work predictions in the FCE work system material they investigated. The researchers concluded that a large number of errors existed in the FCE prediction of full-time tolerance, and that the formulas used to predict how much weight could be lifted, and how frequently it could be lifted, were of questionable value.

Abdel-Moty et al.[3] reviewed the relationship between medical impairment, functional capacity, and residual functional capacity. They concluded that a major conceptual error existed in trying to translate the functional capacity evaluation results from a 1- to 2-hour test into a prediction of how well an individual could tolerate 8 hours of work. The authors also noted that there was evidence in the scientific literature, primarily in psychophysical methods, that indicated that an individual's ability to handle loads over time would require evaluation methods that included the assessment of heart rate.

Standardization

A standardized FCE process has been promoted by Hart et al.[5] which when reviewed, by the author, was found to lack work physiology, and in particular, a method for predicting full-time work tolerance. **Review of the work by Lechner et al.,[7] concluded that there was no standard for comparing test components, and that determination of effort was made by an observation of the therapist. A review of the Lechner et al.[7] material, PWPE, demonstrated no evidence of a standardized work physiological process or calculation for work tolerance prediction.** Tramposh[9] reviewed materials from the *Commission on Accreditation of Rehabilitation Facilities* (CARF) and noted that definitive work physiology protocols, as well as promotion for a uniform standard of FCE service, were lacking. **However, Tramposh concluded that FCEs in general suffer from a lack of objective data, and therefore, could not accurately predict a worker's success in actual full-time job-related functions.**

Hart, Isernhagen, and Matheson[4] provided relatively vague guidelines for the inclusion of tests for the FCE. The authors stated that an individual's potential for sustained work is predicted rather than measured directly, and that a safe and dependable performance level is a professional judgment.

Smith, Cunningham, and Weinberg,[11] in a discussion of the kinesophysical method endorsed by Hart, Isernhagen, and Matheson,[4] found that additional research was needed to document the reliability of the end point in FCE testing.

Several authors and institutions note that expertise is the primary prequisite to performing exercise testing, intrepreting results, providing safeguards, and providing valid and reliable testing.[10,12,13] King et al.[6] drew attention to the same need for expertise in FCE testing, particularly in utilizing a scientific approach to predicting an individual's ability to tolerate an 8-hour work day.

The Difference Between Clinical Exercise Testing and Work Physiology Testing

Exercise Testing:

The exercise test procedure is defined as a diagnostic tool, a prognostic tool, and a therapeutic interpretative application used for exercise prescription.[12] The selection of the protocol should be specific for the purpose of the test, the outcomes desired, and the individual being tested. *The American College of Sports Medicine* (ACSM)[12] and other authors,[14] have identified relative contraindications for *graded exercise testing* (GXT), including neuromuscular, musculoskeletal, or rheumatoid disorders that are exacerbated by exercise. In the realm of FCE testing procedures, the exposure of a patient to GXT by the therapist would be a sign of relatively poor understanding of the difference between work physiology and exercise testing. **During an exercise test, the subject is asked to continue with the test until they are too fatigued to continue, or until they experience any alarming symptoms.[14] This result would be undesirable in an FCE setting, where many individuals under examination have a history of the contraindicated symptoms identified by the ACSM for GXT testing.** In contrast to exercise testing, the work physiological test determines how the effort expended to perform the test reflects the subject's ability to work full-time. When exercise test procedures are evaluated, the data reveals that the protocol included an intensity of exercise at a predetermined rate that can be as great as 80% to 85% of a patient's maximum heart rate; this level of exposure is considerably greater than the highest work physiological expectations required for 8 hours of work.

The GXT exercise tests procedures that monitor heart rate used for clinical evaluation, clinical prognostication, and preparation of exercise regimentation are referred to as Heart Rate Methods.[12,16] Heart rate methods include the Direct Method, the Heart Rate Reserve Method, also called the Indirect Method or Karvonen Method, and the Percent of HRmax (Table 1). The Direct Method monitors the heart rate at each stage of a maximal GXT. The Indirect Method, or Heart Rate Reserve GXT Method, is the difference between the resting and the maximal heart rate. The heart rate reserve (HRR, or submaximal test), is determined by subtracting the resting heart rate from the maximal heart rate to obtain the HRR. The HRR is then multiplied by 80% and subsequently by 60% for a defined range of GXT heart rate response to determine the termination of testing procedure. The adjusted value of HRR is then added to the resting heart rate. The Indirect Method is also adjusted for age, as required by the test procedure, using the value of 220 and subtracting the age. The final method, Percentage of Maximal Heart Rate, is a fixed-percentage heart rate method. The percentage is typically 75% to 85%. These GXT submaximal tests are terminated at a predetermined rate by the percentage selected by the examiner, so that the outcome can be used for development of a heart rate (HR) - based exercise training prescription.

Work Physiology Review:

The most important characteristic of an industrial physiological measurement is that it must be relatively uncomplicated so that administration and interpretation are effective. The procedure must use accurate and reliable data, which is easily obtained, and for that reason, heart rate is the variable of preference.[15,17] A number of researchers endorse using heart rate as the primary measurement criteria, because it has been demonstrated to have a linear relationship with energy expenditure and can be measured without interfering with the work task in progress.[17,18] The physiological approach to an individual's work response is used as a measure of the heaviness of the task and the sustainable capacity for task completion.[20] **Heart rate is also the best index for physical work[10,18] because it is reasonably similar for all persons during performance of work.**[26,27,28] Even during moderate to strenuous work, physiological monitoring of the heart rate is the best index of the stress imposed by the task.[19,21]

The concept of steady state work efficiency is considered a linear value, and the concept of steady state work physiological response measured by heart rate is also considered a linear value. When both the steady state work efficiency and work physiology have corresponding parallel linear responses the individual is considered to have full-time work tolerance. In any given person, a linear relationship exists between oxygen consumption and heart rate.[10,15,18,28,30] The mean value for heart rate at a given submaximal task is the same for individuals of the same sex and state of training, regardless of age.[10,15,21,22]

When work is not considered to be heavy, the heart rate response exhibits a steady-state for individuals who are not burdened by disease.[18,24] The efficiency of physiological work is defined by researchers as the percentage of energy that is transformed into useful sustainable work.[10,17,18,27] The sustainable work level that is linear can be maintained without excessive fatigue and has been labeled the *limit of continuous work* (LCW).[21,24] The criterion of work heart rate is defined as the difference between the resting heart rate and the heart rate monitored while the individual is working.[25]

The expected ranges of sustainable work have been reported by numerous authors.[10,13,15,22,24,30] The basic premise of performance is that a workload of 30% to 40% is typical in full-time industrial settings. Limited tolerance is found for work levels in which 50% of oxygen consumption is required, and this corresponds to a heart rate of 130 beats per minute.[10] The typical workload heart rate in linear sustained functions was found to be in the range of 90 to 115 beats per minute.[21,24] At the lower range of this heart rate, 90 to 92 beats per minute, oxygen consumption was recorded at 21% to 25%.[15,20,24] In healthy individuals, a workload consisting of 25% maximal oxygen was not enough to cause symptoms or signs of general physiological fatigue.[10,18,20,24,25] The 45% oxygen consumption rate was identified to be tolerated for 2 hours[27] and is associated with a heart rate of 125 beats per minute,[27] while an oxygen consumption rate of 50% consumption was associated with heart rate of 130 beats per minute.[27] Jiang[20] reported that a heart rate of 140 to 150 beats per minute was most limiting, with a tolerance of less than 1 hour.[20] Typical continuous performance was found to be 30 to 35 beats per minute above the resting level with a mean oxygen consumption of 33%.[17] Jobs that exceeded 33% oxygen consumption were found to be structured so that lighter work functions, having a rate less than 30%, were introduced.[25]

The average rate of oxygen consumption during the course of a full work-day is 33% at heart rates of 100 to

Table 1
Example Equation for GXT Exercise Prescription Testing

Example 1.	True Maximal/Direct Method 220 - Age = Estimated HRmax
Example 2.	Indirect Method / Heart Rate Reserve (HRR / Karvonen) Max HR = 220 - age Max HR - Resting HR = HRR If the GXT prescription is for an 80% heart rate response (HRR x 80% = X) X + Resting HR = Estimated HRmax for GXT testing or If the GXT prescription is for 60% heart rate response, HRR x 60% = Y Y + Resting HR = Estimated HRmax for GXT testing
Example 3.	Percentage of Maximum Max HR x 75% or 85%

These protocols, or variations thereof, have been utilized by FCE providers[1,2] but are clearly not intended for use of work prediction tolerance.

Max HR = Maximun Heart Rate

112 beats per minute.[17,20,27] For 1 hour of continuous heavy work, 50% or greater oxygen usage is predicted; for 20 minutes of very heavy work, 70% oxygen usage is predicted; and, for extremely heavy work over the course of 10 minutes, 85% oxygen usage is predicted.[21,29] Other authors cite the limits of oxygen usage as 63% for 1 hour of very heavy work, 53% for 2 hours of heavy work, 47% for 4 hours of moderate work, and 33% for 8 hours of light work (Table 2).[20,27,29]

If the burden placed on the worker is too high in relation to their capacity for sustained physical work, the individual will become fatigued. Perry[22] noted that a decrease in oxygen consumption, and therefore in the individual's ability to tolerate work, occurs when they have cardiovascular, metabolic, or muscular system disease. Bassey, MacDonald, and Patrick[31] reported that an individual's physical tolerance to work is inversely proportional to his/her physical condition. When the worker's condition was tolerant to the standard intensity of work, sustainable physiological response was measurable by heart rate. However, when the physiological requirements of the work exceeded the tolerance of the individual, the heart rate elevated over time while the work function decreased. Demeter and Andersson[19] noted that an inverse relationship existed between the ability to sustain a task and the percentage of work required. They determined that, as the task became more demanding, the workers neared their maximum heart rate; as this occurred there was an exponential decrease in work-time tolerance. The total amount of work performed by the individual decreased substantially when the work requirement exceeded physiological tolerances. Thus, the endurance of the work requirement is an event that can be monitored by measuring linear and longitudinal heart rates or the aberration from that expectation. **The closer the task is to the worker's maximum capacity, the shorter the length of time an individual can work.**

Various authors determined that if work begins in a tolerable range, the motor speed of performing the work reaches the steady-state function in approximately 30 seconds to 3 minutes.[10,28,32] Subsequently, the heart rate reaches a steady-state after 4 to 5 minutes (Fig. 1). The value of the heart rate in the 5 to 6 minute timeframe is designated as the working pulse rate.[10,26,28,32] The close association between oxygen consumption elevation and the heart rate from the first to fifth minute of work indicates that the stimulus and resultant are closely related. The degree of demand depends on the rapidity of the work requirement and the heart rate output.[26]

Calculations for Determining the Heart Rate in Relation to the Percentage of Aerobic Capacity

According to Kodak[29] and Rodahl,[13] the heart rate is closely related to the percentage of maximum aerobic capacity as a function of maximum oxygen consumption. The oxygen response of an individual can be shown in relation to the predicted maximum heart rate. The predicted maximum heart rate is estimated by subtracting a person's age from 220. An individual's maximum heart rate value declines with age—one beat per minute per year. To estimate the percentage of maximum heart rate required by a job or job activity, the following formula can be applied:

- **(AHRJ-RHR)/(PHRM-RHR) = % aerobic capacity[29]**
- **AHRJ = Actual heart rate job,**
- **RHR = Resting heart rate, and**
- **PHRM = Predicted heart rate maximum,**

in which the numerator is the heart rate elevation, and the denominator is the individual's heart rate range. The quotient of the equation is the percent maximum aerobic consumption required on the job. Examples are listed in Table 3.

Table 2
Classification of Work By Heart Rate and Severity

Example 1. Astrand et al.[15]

Workload	Heart rate, beats/min
Light Work	up to 90
Moderate Work	91–110
Heavy Work	111–130
Very Heavy Work	131–150
Extremely Heavy Work	151–170

Example 2. Williams[17]

Workload	Heart rate, beats/min
Very low	75
Low	76–100
Moderate	101–125
High	126–150
Very High	151–175
Extremely High	176+

Example 3. Kroemer & Grandjean[25]

Workload	Heart rate, beats/min
Very low	60–70
Low	75–100
Moderate	101–125
High	126–150
Very High	151–175
Extremely High (e.g., sport)	176+

Example 4. Wilson & Corlett[30]

Workload	Heart rate, beats/min
Light	up to 90
Moderate	91–100
Heavy	111–130
Very Heavy	131–150
Extremely Heavy	151–170

Example 5. Jiang[20]

Workload	Percent Work	Work Duration	Heart Rate beats/min
Moderate	<33%	8 Hrs	90-110
Heavy	34%–50%	8 > 1 Hrs	111–130
Very Heavy	51%–75%	1 Hr > 20 min	131–150
Extremely Heavy	> 75%	< 20 min	> 150

Example 6. Kodak[29]

Workload	Percent Max Aerobic Capacity	Heart Rate Elevation beats/min above rest
8 Hours	33%	+35
1 Hour	50%	+55
20 Min	70%	+75
5 Min	85%	+90

Table 3
Calculations for Determining the Heart Rate in Relation to the Percentage of Aerobic Capacity

Example:
Work requirement is 33% aerobic capacity: 8 hours
Age of worker is 50 years
Resting heart rate is 70 beats/min

Calculate the average heart rate of this worker on the job:
AHRJ = X
RHR = 70
PHRM = 220 - 50 = 170

The formula for solving the calculation is:
(X - 70) / (170-70) = 33% (or .33)
(X - 70) / 100 = .33
(X - 70) = .33 x 100
X - 70 = 33
X = 33 + 70
X = 103
(Answer: 103 beats/min is the expected heart rate for the worker to be able to sustain 8 hours of continuous work)

Alternate formula:
Work requirement is 33% aerobic capacity: 8 hours
Age of worker is 50 years
Resting heart rate is 70 beats/min

(220 - age) - (resting HR) x .33 = X; X + resting HR = work HR
(220 - 50) = 170
170 - 70 = 100
100 x .33 = 33
33 + 70 = 103 beats/min

These formulas can be accurately applied in predicting tolerance of full time work. The calculated heart rates are compared to Table 2 examples to determine if the worker can be employed full time.

Reviewing Actual Data from Commercial Capacity Evaluation Providers and Determining Accuracy of that Information

The Blankenship[1] cardiovascular endurance data calculation for the age-adjusted predicted heart rate is shown in Table 4. "Occasional" is a term used in vocational applications to mean 33% of the typical 8-hour working day, or approximately 2.5 hours. The Blankenship[1] FCE calculation for 'Occasional Material Handling' predicts a heart rate of 153 beats/min. According to Jiang,[20] classification of work by heart rate and severity (Table 2, Example 5) identifies the 2.5-hour work tolerance to range between 124–130 beats/min, and is classified as "Heavy Work." In Example 5 (Table 2), the heart rate of 153 beats/min determined by the Blankenship FCE would categorize the data as "Extremely Heavy Work," with a duration of less than 20 minutes in an 8-hour work day. The Blankenship FCE calculation of work-time tolerance is inconsistent with the data from Table 2. Therefore, the Blankenship FCE protocol is incorrect as a method for calculating work-time tolerance in the Occasional category.

The Blankenship[1] FCE calculation for the age-adjusted maximum predicted heart rate (Table 4) is found to be flawed in comparison to classification of work by heart rate and severity (Table 2). In Table 4, the Blankenship FCE calculation for cardiovascular endurance is identified to be 63% of a worker's maximum oxygen consumption. **The Jiang[20] and Kodak[29] data show that endurance of an 8-hour work day requires a maximum oxygen consumption of 33%.** Therefore, the Blankenship calculation of a maximum oxygen consumption of 63% as representative of a worker's endurance for full-time work is incorrect when compared to the data of Jiang[20] and Kodak.[29] According to Table 2, Example 5, a maximum oxygen consumption level of 63% represents a work-time value of approximately 40 minutes. By using the information provided in Table 1 and 2, the vocational counselor will be able to determine if FCE reports they are examining accurately identifies the ability of the worker to be employed full-time. Within the protocols of work physiology, the capacity test procedure samples the tolerance of the individual being examined, which then reflects the adaptation to function that has occurred externally to the test facility. In the presentation of clinical signs, pain symptoms, or other maladies, the tasks pursued on an everyday basis require physiological expenditures. The history of actual human performance functioning beyond the test facility is borne by the oxygen consumption requirement of the body during the test procedure.

Table 4
Blankenship Cardiovascular Endurance Data Collection

Example:

Worker is 40 years of age.
Age-Adjusted Max Predicted HR = 183 bpm
Final Working HR= 115 bpm

Cardiovascular Endurance Data Calculation = Final Working HR / Age Adjusted Max HR

115 / 183= 63%

63% is the Cardiovascular Endurance for Work

Summary and Conclusions

As scientific disciplines, work physiology and human performance fulfill many aspects of the objective quantification process for determining vocational applications regarding full-time work tolerance.

The following principles are understood:

- **The heart rate response, in relation to work prediction and compared with the resting heart rate, can be used as an interpretative tool for capacity evaluation test reviewers.**
- **FCE testing protocols evaluate an individual's ability to work full-time. The worker being evaluated by the FCE protocol has adapted over time to the injuries, diseases, or other maladies of their individual situation. On a daily basis, these injured workers pursue various activities, tasks, or types of employment, all of which have different oxygen consumption requirements. The FCE testing protocol exposes the individual's musculoskeletal system to conditions which simulate work, and demonstrate how the injured worker has adapted to his/her situation by measuring the subject's rate of oxygen consumption. This is accomplished by comparing the heart rate response monitored during FCE tasks to established data for physiological work tolerance. By comparing an individual's actual heart rate during FCE tasks to work tolerance data, counselers can determine the actual capacity of the individual for work.**
- **Deviations from linear and longitudinal physiological profiles allow an examiner to effectively determine the physical tolerance of the individual for sustainable work. Deviations from normal physiological profiles permit the vocational professional to determine if the injured worker has a barrier (or barriers) which will require adaptations or accommodations in order to be considered a candidate for work placement.**
- **Work physiological monitoring can be used as a predictor of the intent of the individual being examined to participate. A minimal elevation of heart rate response above the resting level indicates minimal recruitment of the muscular system. The presentation of high heart rate during work sampling indicates a cooperative effort by the individual being examined. Excessive elevation of heart rate can serve as a sign of disease process or clinical dysfunction requiring professional service interventions. It is the responsibility of vocational professionals to be aware of various scientific foundations upon which work prediction tolerances are determined, such that their opinions are not compromised.**

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Questions Based On This Lesson

To earn CE credits, answer the following questions on your quiz response form.

61. According to the lesson, why is GXT an undesirable alternative to a *functional capacity evaluation* (FCE)?

A. GXT is too time consuming.

B. GXT is expensive and never covered by medical insurance.

C. Many individuals under examination in an FCE setting have a history of symptoms contraindicated for GXT.

D. Most clinicians are unfamiliar with GXT.

62. Why is heart rate considered the best index for physical work?

A. Because it is reasonably similar for all persons during the performance of work

B. Because it is the most uncomplicated method of measurement

C. Because it is the least invasive method of measurement

D. Because it varies from person to person, providing a more definitive result

63. Which of the following is *not* a principle of physiological response:

A. The heart rate maximum decreases one beat per year as age progresses.

B. The maximum predicted heart rate never changes.

C. Oxygen consumption at a 33% level is considered to indicate tolerance for full-time work.

D. Oxygen consumption at a 25% level is considered to indicate tolerance for full-time work.

64. Excessive heart rate elevation during FCE points to:

A. A strong, healthy, heart

B. Heart disease or defect

C. A testing error

D. None of the above