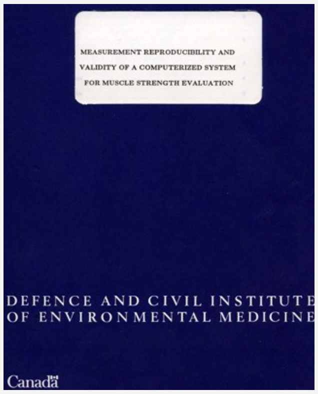
Validity of the ACES

Measurement Reproducibility and Validity of the ACES



Code	**adi-pub-01273**
Title	Validity of the ACES
Subtitle	Measurement Reproducibility and Validity of the ACES
Name	Defence and Civil Institute
Author	I. Jocobs and J.Pope
Published on	Sunday, January 20, 1985
Subject	ACES; Exercise Machine; Favorite; Journal
URL	https://arielweb.com/articles/show/adi-pub-01273
Date	2013-01-16 15:40:52
Label	Approved
Privacy	Public

This PDF summary has been auto-generated from the original publication by arielweb-ai-bot v1.2.2023.0926 on 2023-09-28 03:44:14 without human intervention. In case of errors or omissions please contact our aibot directly at ai@macrosport.com.

Below find a reprint of the 21 relevant pages of the article "Validity of the ACES" in "Defence and Civil Institute":

MEASUREMENT REPRODUCIBILITY AND
VALIDITY OF A COMPUTERIZED SYSTEM
FOR MUSCLE STRENGTH EVALUATION

DEFENCE AND CIVIL INSTITUTE OF ENVIRONMENTAL MEDICINE

Canada

JANUARY 1985 DCIEM No. 84-C-75

MEASUREMENT REPRODUCIBILITY AND VALIDITY OF A COMPUTERIZED SYSTEM FOR MUSCLE STRENGTH EVALUATION

I. Jacobs
J. Pope

Defence and Civil Institute of Environmental Medicine
1133 Sheppard Avenue West, P.O. Box 2000
Downsview, Ontario M3M 3B9

DEPARTMENT OF NATIONAL DEFENCE - CANADA

UNCLASSIFIED

TABLE OF CONTENTS

ABSTRACT

This report describes the reproducibility and validity of a computerized muscle strength evaluation system, the Ariel Computer Exercise (ACE) system. Force measurement was examined on three trials on each of three separate days by comparing the ACE readout of an applied force to known calibration weights applied to the ACE. Angular velocity was examined by comparing various velocities chosen via ACE software commands to the actual velocity of the ACE lever arm measured with a micro-switch activated timer. Intra-subject reproducibility was evaluated by having six subjects perform maximal contractions on three separate days at various angular velocities. The results indicate that reproducible and valid force measurements and angular velocities are achieved with the ACE provided the system is calibrated according to the manufacturer's specifications at least once daily.

INTRODUCTION

This laboratory recently initiated a research programme in the area of human skeletal muscle strength and power. Within the framework of such a multi-faceted topic, it was envisaged that both basic and applied research would be carried out to investigate adaptations to strength training as well as the acute physiological responses to such exercise. After examining the various muscle strength testing apparati commercially available, the Ariel Computer Exercise (ACE) system (Ariel Dynamics, Inc.) was purchased.

Since it is envisaged that the ACE will be used as a measurement tool for future research, documentation of this equipment's precision and reliability will be required for reference purposes. The ACE, however, has only recently become commercially available and there are no published data with regard to measurement validity and reproducibility, nor are there normative values available for comparative purposes. This report is descriptive in nature; it will describe our tests of the validity and reproducibility of force measurement and angular velocity control by the ACE. The day-to-day variation in peak torque generation during maximal voluntary contractions (MVC) will also be documented. In addition, various muscle groups have been tested with standard exercises on the ACE in our laboratory and the recorded data have been reduced and are presented for future reference.

METHODS

Equipment description. The two exercise units which comprise the ACE are the multifunction unit (MF, Figures 1,2) and the arm-leg unit (AL, Figures 3,4). Each unit consists of the following arrangement of components:

1. Two-way single-rod-end hydraulic cylinder;

2. Rotary hydraulic spool valve for controlling the flow of fluid through the hydraulic system;

3. DC stepper motor (bi-directional) for turning the hydraulic valve;

4. Hydraulic connector block, used to connect various hydraulic components in the proper configuration;

5. Hydraulic check valves to permit flow of fluid in one direction only;

6. Pressurized fluid reservoir, to accommodate fluid volume changes due to movement of single-rod-end cylinder;

7. Brackets for attaching cylinder assembly to frame and bar;

8. Supporting frame for exercise machine;

9. The bar is assembled in such a way that it pivots at the frame where it is attached to the rod of the hydraulic cylinder. Movement of the free end of this bar causes the piston to move in the hydraulic cylinder;

10. Detachable handles, pads, plates, etc., as a means of interfacing the moveable bar to the user;

11. Pressure transducer for measuring force on the hydraulic piston through a measurement of hydraulic fluid pressure;

Figure 1. The ACE multi-function unit with subject initiating supine bench press.

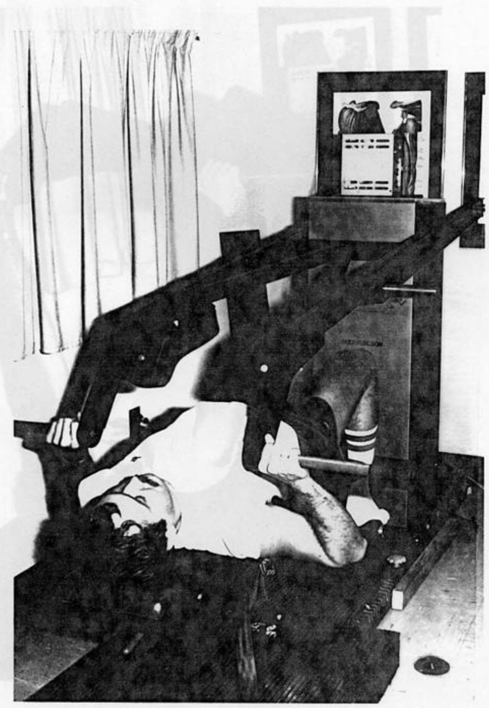


Figure 2. The ACE multi-function unit with subject completing bench press.

Figure 3. The ACE arm-leg unit with subject initiating knee extension.

Figure 4. The ACE arm-leg unit with subject completing knee extension.

12. Angular displacement transducer, consisting of a potentiometer coupled to the rotating pivot shaft of the bar;

13. A/D converter for translating voltage levels from the transducers (numbers 11 and 12 above) to digital values readable by the computer;

14. Stepper motor driver, for converting digital pulses from the computer to the proper power switching sequence for driving the stepper motor in the forward or reverse directions;

15. Stepper motor power supply;

16. Computer consisting of central processing unit, internal memory, multiple display interface, printer interface, A/D converter interface, digital output interface, extended secondary memory (disks), appropriate power supplies, and cabinet;

17. Color graphics display;

18. Keyboard for display;

19. Light pen for display;

20. Line printer.

Functional description. The user of the ACE grasps the handles, or positions wrists, ankles, shoulders, etc., between or under pads attached to the moveable bar(s). Exercise consists of alternately pulling and pushing on the bar so that it pivots about its point of attachment in alternate directions. As the bar pivots, the attached cylinder rod moves the hydraulic piston up or down depending upon the direction of the exercise. As the hydraulic piston moves, fluid is forced out of one end of the cylinder, through the appropriate check valves, through the rotary spool valve, and back into the opposite end of the cylinder. Fluid is shunted to and from the reservoir on the low-pressure side of the spool valve to accommodate the change in volume in the cylinder as the rod moves in and out. This reservoir is pressurized to avoid cavitation on the low pressure side of the piston during rapid movement of the rod. Fluid pressure on the high pressure side of the spool valve is continuously monitored and, since the area of the piston is known, the force on the rod is continuously calculated by the computer. Similarly the angular displacement of the bar is continuously monitored by comparing the voltage output of the potentiometer with the reference voltage at the limits of excursion. In addition, velocity and acceleration of the bar are also computed continuously based on sequential readings of displacement measured against the precision real-time clock in the computer.

With the spool valve fully open the bar moves freely. As the spool valve is closed, there is increasing resistance to the flow of hydraulic fluid in the system, and, therefore, increasing resistance to moving the cylinder rod and the bar attached to it. When the valve is closed, the cylinder cannot be moved, and the bar is locked in position. Due to the construction of the cylinder and the arrangement of check valves, this sytem yields a resistance in either direction of motion. The direction of motion may be reversed at any time without the mechanism having to change modes or configuration, other than perhaps an adjustment of the spool valve to yield the appropriate resistance for the given direction of motion.

The software which controls the ACE readily permits lever arm motion in an isokinetic mode (by limiting angular velocity to a selected upper value), in an isotonic mode (by resisting movement until a selected resistance is overcome), or in an isometric mode (by locking the lever arm in the desired position). The software also allows several changes in velocity or resistance to be programmed at the user's discretion within a single contraction or range of motion. Among the variety of maneuvers which can be readily executed for large muscle group strength evaluation are the following: horizontal or inclined bench press, sitting or standing press, latissimus dorsi pull-downs, biceps curls, triceps extensions, bent-over or upright rowing, squats, sitting knee extensions and flexions, standing calf raises.

Validity and reproducibility of force measurements. Before testing, a simple calibration procedure recommended by the manufacturer was performed and the results were automatically registered and stored on the controlling software diskette. This procedure involved hanging calibration weights on the lever arms. After this calibration a different series of known weights ranging from 10 to 50 kg were hung on the lever arm to apply force. The known force values were compared to the values recorded and displayed by the ACE and the differences were compared with a paired t-test.

The reproducibility of these measurements was established by hanging various calibration weights on the lever arm three times per day on each of three separate days within one week. The data were tested with an analysis of variance for repeated measures (ANOVA), contrasting within-day and across days mean values. The location of statistical significance ($p<0.05$) was determined with a Duncan Multiple Range Test.

Intra-subject reproducibility was established by having six subjects perform maximal voluntary sitting knee extensions on the AL machine at angular velocities of 30, 100 and 200 °/s. These exercises were performed at identical times on three consecutive days. The first session was considered a familiarization trial. The second and third day values were used for the calculation of a method error and coefficient of variation as described by Sale et al. (1).

Validity and reproducibility of angular velocities. A micro-switch assembly was used to start and stop an electronic timer accurate to 10^{-3}s. After inputting the appropriate software commands to choose the desired velocity, a weight was hung on the end of the MF lever arm 140 cm from the axis of rotation. The micro-switch which activated the timer was placed in the middle of the MF unit's range of motion. The second switch which stopped the timer was placed at a point exactly 10° further along the arc of lever movement. These positions were chosen to approximate the normal range of motion of most subjects for the majority of exercises routinely performed on the ACE MF unit. In this manner, the angular velocities were timed directly when a constant 50 kg weight was hung on the lever arm with chosen velocities of 10, 20, 30, 40 and 50 °/s. This procedure was repeated three times on each of three consecutive days. A velocity calibration was performed in accordance with the manufacturer's specifications prior to the first trial only. These data were also tested with an ANOVA and the Duncan Multiple Range test.

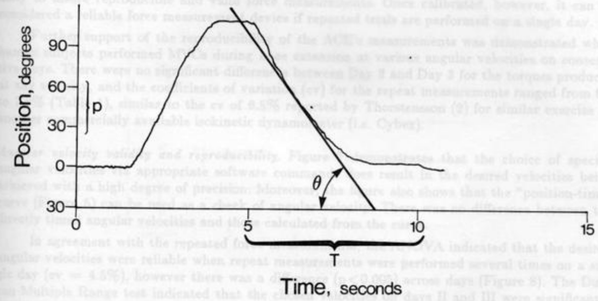
The manufacturer suggests that angular velocity can also be calculated from a hard copy print-out of the "position vs. elapsed time" graph which is printed at the user's discretion (Figure 5). The angular velocities which were timed directly as described above were compared with the velocities calculated using the graph and the following formula:

$$v = 4.1667 \text{ x } [\tan \theta \text{ x } P/T]$$

where v = angular velocity, θ = the angle created at the intersection of a line extending from the linear portion of the position curve to the time axis, P = the difference between successive scale markings on the position axis, and T = the difference between successive scale markings on the time axis (Figure 5). The angular velocities calculated with the formula were compared with the directly timed velocities and with the desired velocities chosen with software commands with paired t-tests.

Peak forces and torques during various exercises. Twenty-three male and eleven female military recruits performed maximum voluntary contractions during unilateral knee extension and flexion on the AL unit and bilateral elbow flexion, leg squats, and supine bench presses on the MF unit. The peak torque values during a slow and relatively fast angular velocity were recorded for each exercise. In addition, the rapid sampling rate of the ACE (i.e. 16,000 Hz) enables a registration and display of average torque throughout the range of motion.

Figure 5. Example of a printout from the ACE multi-function unit showing torque and lever-arm position plotted against time. The figure depicts the lever- arm being passively raised from the horizontal position (relative position 0°) to a vertical position (relative position > 90°) where the application of a constant force then pushes the lever-arm back to the horizontal position.



RESULTS AND DISCUSSION

Force validity and reproducibility. The ACE proved to be a valid force measurement apparatus. After calibration, the forces registered by the ACE were not significantly different from the known weights hung on the lever arm. These results are depicted in Figure 6 where the calibrated weights can be compared to the recorded forces on trial I. The difference between the mean of the known weights and the ACE registered values was insignificant when tested with a paired t-test. The ANOVA revealed that there was not a difference across trials within a single day when five calibration weights were used during three trials on each of three consecutive days. The ANOVA did, however, reveal highly significant differences across the three days ($p<0.001$). A Duncan Multiple Range Test subsequently indicated that all three days differred significantly from each other. Figure 6 demonstrates that there was a progressive decrease in the ACE registered forces compared to the known weight values. Although we cannot be certain whether the pattern would have continued with time or levelled off, the results suggest that the ACE must be calibrated daily to insure reproducible and valid force measurements. Once calibrated, however, it can be considered a reliable force measurement device if repeated trials are performed on a single day.

Further support of the reproducibility of the ACE's measurements was demonstrated when human subjects performed MVCs during knee extension at various angular velocities on consecutive days. There were no significant differences between Day 2 and Day 3 for the torques produced at any velocity, and the coefficients of variation (cv) for the repeat measurements ranged from 0.4 to 7.8% (Table 1), similar to the cv of 6.5% reported by Thorstensson (2) for similar exercise on another commercially available isokinetic dynamometer (i.e. Cybex).

Angular velocity validity and reproducibility. Figure 7 demonstrates that the choice of specific angular velocities via appropriate software commands does result in the desired velocities being achieved with a high degree of precision. Moreover, the figure also shows that the "position-time" curve (Figure 5) can be used as a check of angular velocity. There was no difference between the directly timed angular velocities and those calculated from the curve.

In agreement with the repeated force measurements, the ANOVA indicated that the desired angular velocities were reliable when repeat measurements were performed several times on a single day (cv = 4.5%), however there was a difference ($p<0.005$) across days (Figure 8). The Duncan Multiple Range test indicated that the chosen velocities on days II and III were significantly faster than on Day I. Days II and III did not differ from each other. These results further emphasize that the manufacturer's calibration procedure should be executed at least once before each day's testing. It should be pointed out that the variation for the timed angular velocities was greatest at the faster velocities. This was probably at least partially due to our use of a constant 50 kg force application when velocity was timed. It is possible that the limited range of motion was not sufficient for the lever arm to reach a maximal velocity with only 50 kg of applied force.

Torques and forces during various exercises. Table 2 presents the recorded peak and average torques during knee extension and flexion, extending from 90° to 180° and flexing back to 90° at various velocities. The results are very similar to those recently reported for a similar group of military recruits who performed similar isokinetic exercise on a Cybex (3).

The various MF exercise results are shown in Table 3. These latter values have been expressed as kg force, not torque, in order to avoid confusion for the reader familiar with Cybex exercise data. The MF unit lever arm's axis of rotation is not aligned with an anatomical axis of rotation, in contrast to Cybex testing and testing with the ACE AL unit. The MF lever arm is much longer than are any anatomical levers permitting greater torque to be generated than is the case with similar force application on the Cybex. For example, performing unilateral elbow flexion with a force of 10 kg and a lever arm length of 30 cm from the elbow to the middle of the palm would result in a torque generation of 29.4 Nm on the Cybex. Elbow flexion with the same 10 kg of force would result in torque of 137.2 Nm on the ACE MF unit.

Figure 6. Changes in force registered by the ACE when calibration weights (known mass) are applied repeatedly during three days.

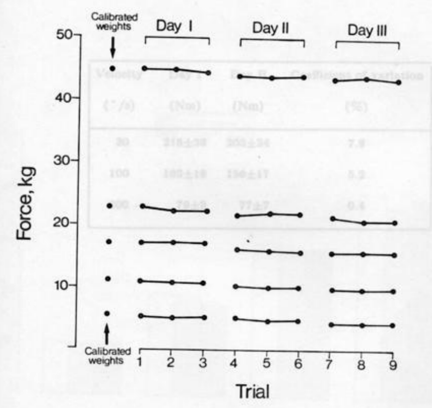


Table 1. **Reproducibility of peak torque (mean±SD) during maximal sitting knee extensions at various angular velocities on two consecutive days.**

Velocity (°/s)	Day I (Nm)	Day II (Nm)	Coefficient of variation (%)
30	216±38	203±34	7.8
100	162±18	159±17	5.2
200	79±9	77±7	0.4

Figure 7. Comparison of lever-arm angular velocities requested via ACE software commands, the actual velocities as directly measured, and the calculated velocities from the "position vs. time" graph shown in Figure 5.

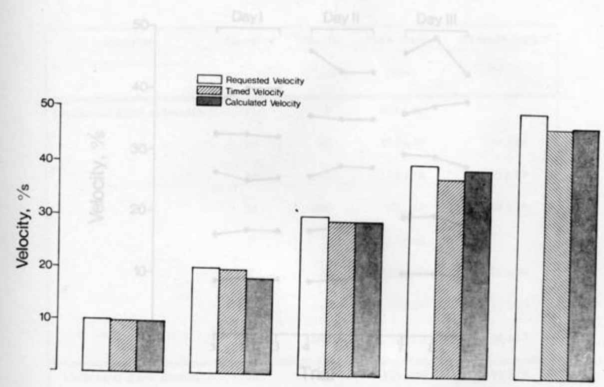


Figure 8. Changes in directly timed angular velocities while the software specified velocity settings remained constant during three days.

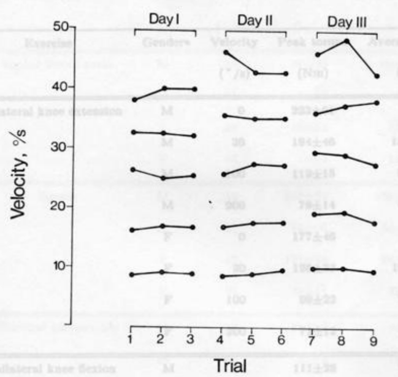


Table 2. **Peak and average torques (mean±SD) during isokinetic maximum voluntary contractions on the ACE Arm-Leg unit.**

Exercise	Gender*	Velocity (°/s)	Peak torque (Nm)	Average torque (Nm)
Unilateral knee extension	M	0	223±61	
	M	30	184±46	150±43
	M	100	119±15	83±19
	M	200	76±14	42±14
	F	0	177±46	
	F	30	126±33	103±29
	F	100	98±22	72±22
	F	200	71±12	46±13
Unilateral knee flexion	M	30	111±28	79±16
	M	100	85±17	71±17
	M	200	66±17	54±13
	F	30	80±19	53±15
	F	100	64±13	49±12
	F	200	55±12	40±13

* (n=23 males, 11 females)

Table 3. **Peak and average forces (mean±SD) during isokinetic maximum voluntary contractions on the ACE Multi-Function unit.**

Exercise	Gender*	Velocity (°/s)	Peak force (kg)	Average force (kg)
Supine bench press	M	10	87±20	63±16
	M	45	32±7	17±5
	F	10	45±11	30±8
	F	45	18±4	10±3
Squats	M	10	187±50	135±39
	M	45	75±28	40±13
	F	10	127±24	96±23
	F	45	38±11	22±6
Bilateral biceps curls	M	10	63±16	41±8
	M	45	23±6	14±4
	F	10	36±8	23±5
	F	45	14±4	9±4

* (n=23 males, 11 females)

CONCLUSIONS

Our experience to date with the ACE confirms that it performs valid and reproducible force measurements. When used for testing isokinetic muscle strength, it limits angular velocity to a user specified velocity with a high degree of precision and reliability. The manufacturer's calibration procedures should be performed prior to each day's use of the ACE to ensure precision.

In light of the measurement reproducibility and validity documented in this report, the ACE can be confidently used for research. The detection of changes in various types of muscular strength due to experimental manipulations, such as different training methods, is greatly facilitated with the ACE. Where several different apparati are usually required to evaluate isokinetic, isometric and isotonic strength, the ACE permits such testing on a single apparatus. Exercise physiology research in a military environment often involves testing of large numbers of subjects in a relatively short period of time. A particular advantage of the ACE for such mass testing is the software control which permits testing protocols and results to be stored and accessed via microcomputer.

Our experience with the ACE includes the recognition of a distinct disadvantage compared to Cybex , another popular isokinetic dynamometer. Although large muscle groups are easily tested on the ACE, smaller muscles cannot be readily isolated for testing purposes without modifications to the apparatus. In contrast, the moveable and adjustable dynamometer head of the Cybex does permit small muscle isolation.

REFERENCES

1. Sale, D.G., and Norman, R.W. Testing strength and power. In: *Physiological Testing of the Elite Athlete*, MacDougall, J.D., Wenger, H.A., and Green, H.J. (eds.). Canadian Association of Sport Sciences, 1982, pp. 7-37.

2. Thorstensson, A. Muscle strength, fibre types, and enzyme activities in man. Acta Physiol. Scand., Suppl. 443, 1976.

3. Knapik, J.J., Wright, J.E., Mawdsley, R.H., and Brawn, J. Isometric, isotonic and isokinetic torque variations in four muscle groups through a range of joint motion. Phys. Ther. 63: 938-947, 1983.