

Does Standing on a Cycle-ergometer, Towards the Conclusion of a Graded Exercise Test, Yield Cardiorespiratory Values Equivalent to Treadmill Testing?

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ABSTRACT

Int J Exerc Sci 3(3): 117-125, 2010. Graded exercise testing (GXT), per a cycle-ergometer (CE), offers safety and monitoring advantages over treadmill (TM) GXT. Unfortunately, CE-VO_{2max} and some other cardiorespiratory (CR) variables are frequently lower than TM-GXT values. It has been difficult to compare TM and CE-GXT values. However, it was hypothesized that standing towards the conclusion of the CE-GXT (Stand-CE) might increase CE values to those equal to TM-GXT. If Stand-CE and TM-GXT CR values were equal, Stand-CE-GXT could become the method of choice for GXT for the general population. The purpose of this investigation was to investigate the effect of Stand-CE on CR variables. An intentionally diverse sample (N = 34, 24 males and 10 females, aged 18-54 y, with VO_{2max} values 25-76 ml/kg/min) representing the “apparently healthy” general population participated. Volunteers completed two GXT trials, one per TM (Bruce protocol) and the other per a MET-TM-matched CE-GXT where initially seated participants stood and pedaled after their respiratory exchange ratio (RER) reached 1.0. Eighteen participants underwent a third MET-TM-matched trial where they remained seated throughout GXT (Sit-CE). Trials were counter-balanced with at least 48 h between GXT. There were significant statistical differences ($p < 0.05$) between TM and Stand-CE per matched-samples T-test (N = 34) on the following variables: VE_{max} (TM = 115 ± 24.4 l/min, Stand-CE = 99.4 ± 28.1), VCO_{2max} (TM = 4.26 ± 0.9 l/min, Stand-CE = 3.56 ± 0.84), VO_{2max} (TM = 44.9 ± 9.1 ml/kg/min, Stand-CE = 39.3 ± 9.0), METS_{max} (TM = 12.8 ± 2.6 METS, Stand-CE = 11.2 ± 2.5), and HR_{max} (TM = 175 ± 13 bpm, Stand-CE = 166 ± 12). One-way repeated measures ANOVA (N = 18) demonstrated no statistical differences among all trials: VE_{max} (TM = 112.8 ± 25.3 l/min, Stand-CE = 102.3 ± 25.2 , Sit-CE = 107.3 ± 33.1), VCO_{2max} (TM = 4.17 ± 0.99 l/min, Stand-CE = 3.62 ± 0.80 , Sit-CE = 3.55 ± 0.83), VO_{2max} (TM = 47.1 ± 9.8 ml/kg/min, Stand-CE = 42.0 ± 9.0 , Sit-CE = 43.3 ± 8.9), METS_{max} (TM = 13.5 ± 2.8 METS, Stand-CE = 12.0 ± 2.6 , Sit-CE = 12.4 ± 2.5), and HR_{max} (TM = 176 ± 13 bpm, Stand-CE = 171 ± 12 , Sit-CE = 173 ± 11). Results of this investigation suggest that TM-GXT CR values are larger than Stand-CE, and Stand-CE values are not different from Sit-CE. Future studies will test validity of these findings per gender, aerobic training status, in populations that are highly skilled with TM and CE (tri-athletes), children, the elderly, and diseased populations.

KEY WORDS: maximal oxygen consumption, stress testing, exercise-mode

INTRODUCTION

Graded exercise testing (GXT) is typically performed per either a cycle-ergometer (CE) or a treadmill (TM) (9). Each modality has its advantages and disadvantages (2, 19). The main advantages of TM-GXT are that participants are, generally, more familiar with walking/running, and maximal oxygen consumption (VO_{2max}) values are typically 10% higher, or even greater in diseased populations, compared with CE-GXT (2, 10, 23). However, TM testing has the disadvantages of being somewhat dangerous (e.g. falling), requiring more expensive equipment, and the exact workload cannot be accurately established (2). In contrast CE offers the advantages of being safer, requiring less expensive equipment, having a known workload, and it is easier to obtain some physiological/clinical measurements (e.g. blood pressure, arterial blood sampling, etc.) (1, 2, 30). The main disadvantage of CE-GXT, as stated above, is that some values, especially VO_{2max} , the critical indicator of aerobic capacity, is lower, except perhaps in trained cyclists, than those obtained per TM-GXT (2, 4, 9). However most CE-GXT have been performed with the subject seated throughout the entire GXT test (30).

Aerobic training status (i.e. low or high VO_{2max}) has been studied during GXT using both TM and CE (2, 7). Typically, TM and CE- VO_{2max} values are higher in aerobically-trained participants, especially runners, compared with a matched (age, body size, etc.) sedentary population (7). Participants with higher VO_{2max} values can exercise to higher workloads and reach steady-state quicker, especially when using TM protocols with relatively large workload

(step/stage) increases, compared with their sedentary counterparts (7). There is some evidence, in trained cyclists, that sitting v. standing increases CE values to equivalent TM values, but this finding has been inconsistent (3, 22, 26). To the best of our knowledge the effect of standing during the terminal portion of a CE-GXT has not been studied in either a trained or sedentary apparently healthy population.

In addition to training status, the effects of gender, even after standardizing to body size (i.e. ml/kg/min), generally demonstrates that males have greater TM and CE- VO_{2max} values compared with aged-matched females (7, 9). This finding is accepted per inspection of well-established TM- VO_{2max} tables where males demonstrate greater VO_{2max} expected/predicted values than females (7). Even though the cardiorespiratory (CR) response to CE and TM-GXT is generally similar between males and females, some variable differences exist (15, 21). But, do these TM v. CE differences remain if participants stand and pedal during the terminal portion of a CE-GXT. To the best of the authors' knowledge, this has not been investigated in an apparently healthy general population (22). The authors hypothesized that if participants stood and pedaled, during the terminal portion of a CE-GXT, crucial CR variables, especially VO_{2max} , might become equivalent in magnitude to TM-GXT values. That is, standing and pedaling would require more energy to be expended due to supporting the body's trunk compared with sitting and pedaling. If standing on a CE during the terminal portion of a CE-GXT increased CR variables, especially VO_{2max} , equivalent values to those generated per TM-GXT, CE-GXT would have the advantages of greater safety, known workload, ease of

physiological monitoring, and higher VO_{2max} values, and become the clinical method of choice for GXT. Also, having CE- VO_{2max} values equivalent to TM- VO_{2max} values would make using well-established TM- VO_{2max} classification tables usable for CE- VO_{2max} testing possible (2, 30). The primary purpose of this investigation was to determine if standing, during the terminal portion of a CE-GXT, would yield CR values equivalent to TM-GXT values in a general population composed of males, females, younger and middle-aged adults, and sedentary and aerobically trained individuals.

METHOD

Participants

An intentionally diverse sample (N = 34, age = 18-54 y; gender = 10 females and 24 males, VO_{2max} = 25-76 ml/kg/min, height = 62-76 in., weight = 128-285 lbs.) was recruited. Participants were screened per questionnaires for exercise readiness (Par-Q), health/disease, and physical activity level (2). Although some of the participants would be classified, per ACSM criteria, as "moderate risk," based simply upon their middle-age status, they would have been classified, per AHA criteria, as "apparently healthy," as none of the participants demonstrated evidence of cardiovascular, pulmonary, or metabolic disease (2, 8). Participants were familiar with running and bicycling, although not all were currently cycling on a regular basis. Personnel trained in ACLS supervised all VO_{2max} tests, and emergency equipment (e.g. defibrillator, oxygen, etc.) was readily available. This investigation was approved by the Institutional Review Board of the University. Participants signed an informed consent prior to participation.

Trials

Three counter-balanced (sequence) trials where participants exercised to VO_{2max} were conducted. The first trial (N = 34, the TM trial) utilized an electronically-controlled treadmill (Quinton Q4500 12-lead EKG system with ST-55 treadmill, Cardiac Science Corp., Seattle, WA) based on the commonly-used Bruce protocol (2, 19). The second and third trials (CE trials) utilized a mechanically braked cycle-ergometer (Monark 828E, Vansbro, Sweden). Prior to the CE trials, participants were acclimated to the CE that included a brief period of low intensity cycling and practice in standing up and pedaling. The CE trials were MET-matched to the Bruce TM protocol (2). The first CE trial (second trial), Stand-CE (N = 34), required participants to stand and pedal after the respiratory exchange ratio (RER) was 1.0 (a readily identifiable physiological point used to identify the terminal portion of a GXT and to standardize the point of standing between participants) of the VO_{2max} test (30). The second CE trial (third trial), Sit-CE, (N = 18) differed from the first CE trial in that the participants remained seated throughout the GXT. For the CE trials, participants were required to maintain pedaling frequency at 60 rpm until their RER was 1.0, and then increase their pedaling rate to 70 rpm for remainder of the trial (10). There was at least 48 hours of rest between all trials (5, 25).

During all trials, in addition to oxygen consumption (VO_2), typical CR variables (minute ventilation, VE ; carbon dioxide production, VCO_2 ; oxygen consumption/heart rate, O_2 -pulse; metabolic equivalents, METS; and ventilatory equivalents for oxygen and carbon dioxide, VE/VO_2 and VE/VCO_2 ;

were measured (Medical Graphics Corp. CPX breath by breath system, St. Paul, MN) using 30 second averaging (7, 12, 30). The so-called anaerobic threshold (AT) was determined, per inspection, and agreement between both the V-slope-plot (ordinate = $V\dot{C}O_2$ v. abscissa = VO_2) method and at the point, after isocapnic buffering, where the VE/VO_2 , VE , and $PETO_2$ increases while $PETCO_2$ decreases (30). During each trial, a 12-lead EKG was monitored for safety purposes and to obtain heart rate (HR) measurements (19). Additionally, when the RER reached 1.0, and at VO_{2max} , blood lactic acid (lactate), was obtained per finger stick and measured (Accutrend Lactate, Sports Resource Group, Roche Diagnostics, Germany). The TM (speed and grade), CE (resistance/load), and lactate analyzer were calibrated regularly throughout the investigation, while the CR analyzers (oxygen, carbon dioxide, and volume/flow) were calibrated immediately prior to each GXT (24).

Statistical Analysis

All data were screened for normality, univariate and multivariate outliers, and homogeneity of variance, prior to statistical analyses (16) using SPSS version 17.0 (SPSS, Chicago, IL). Data for all three trials (N = 34) were analyzed per one-way ANOVA and ANCOVA (using body weight as a covariate). Participants that completed all three trials (N = 18) data were analyzed per one-way repeated measures ANOVA. For the "two trials" analysis, TM v. Stand-CE (N = 34), data were analyzed per matched-samples T-test. For all statistical analyses, the level of significance was $P < 0.05$. All three-trial post-hoc testing was performed per Tukey HSD method (16). Power for all analyses was calculated per SPSS.

RESULTS

Key subject characteristics and the means and standard deviations of CR parameters for the three trials (including grand means and standard deviations) are reported in Table 1. The results of one-way ANOVA, by trial (excluding the grand means), demonstrated statistically significant differences ($p < 0.05$) for the variables $V\dot{C}O_{2max}$, (TM v. both CE trials), VO_{2max} (TM v. Stand-CE), VO_2 at AT (TM v. Sit-CE), $METS_{max}$ (TM v. Stand-CE), and HR_{max} (TM v. Stand-CE).

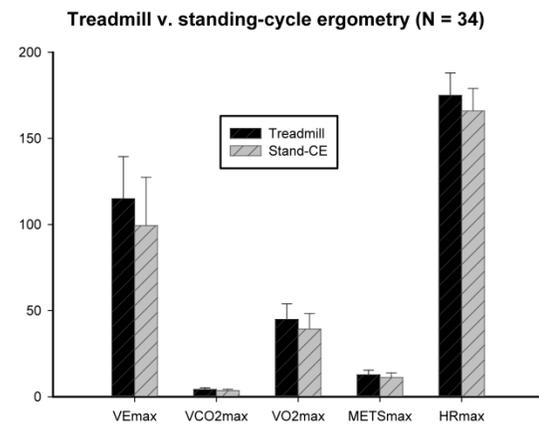


Figure 1. All of the selected variables were statistically different ($p < 0.05$) trial per matched-samples T-test (error bars represent standard deviations).

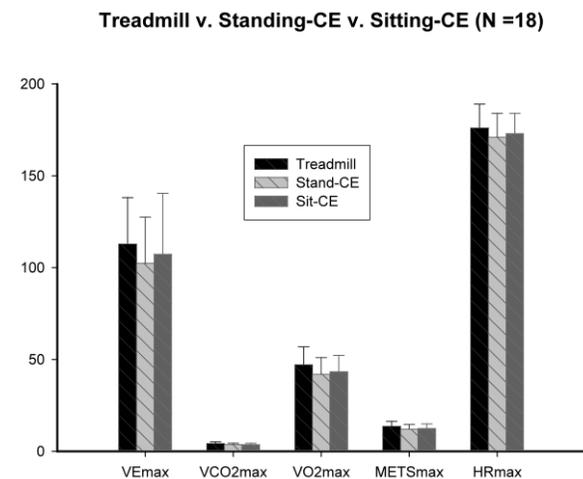


Figure 2. None of the selected variables were statistically different ($p < 0.05$) by one-way repeated measures ANOVA by trial (error bars represent standard deviations).

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Figure 1 illustrates select variables that were statistically different ($P < 0.05$), by matched-samples T-test, between the TM and Stand-CE ($N = 34$) trials. Means and standard deviations for these statistical differences were VE_{max} (TM = 115 ± 24.4 l/min, Stand-CE = 99.4 ± 28.1), VCO_{2max} (TM = 4.26 ± 0.9 L/min, Stand-CE = 3.56 ± 0.84), VO_{2max} (TM = 44.9 ± 9.1 ml/kg/min, Stand-CE = 39.3 ± 9.0), $METS_{max}$ (TM = 12.8 ± 2.6 METS, Stand-CE = 11.2 ± 2.5), and

HR_{max} (TM = 175 ± 13 bpm, Stand-CE = 166 ± 12).

Figure 2 illustrates select variables for the participants that completed all three trials ($N=18$). There were no statistical differences ($P < 0.05$) by one-way repeated measures ANOVA. Means and standard deviations were VE_{max} (TM = 112.8 ± 25.3 L/min, Stand-CE = 102.3 ± 25.2 , Sit-CE =

Table 1. Subject Characteristics and Exercise Variables by Trial.

Variables	Overall	Treadmill	Stand-CE	Sit-CE
Subjects (N)	34	34	34	18
Height (in.)	68.7 ± 3.0	68.7 ± 3.1	68.7 ± 3.1	68.5 ± 3.1
Weight (lb.)	166.5 ± 31.7	168.7 ± 32.9	168.7 ± 32.9	158.3 ± 27.1
Age (y)	24.3 ± 8.6	24.3 ± 8.6	24.3 ± 8.6	24.5 ± 8.8
VCO_{2max} (l/min)	3.83 ± 0.92	$4.26 \pm 0.93a$	$3.56 \pm 0.84b$	$3.55 \pm 0.84b$
VE_{max} (l/min)	107 ± 28	115 ± 24	99 ± 28	107 ± 33
RER _{max}	1.22 ± 0.1	1.26 ± 0.1	1.21 ± 0.08	1.18 ± 0.1
O_2 -pulse (ml/bpm)	18.0 ± 5.0	19.1 ± 5.4	18.0 ± 4.9	17.8 ± 4.4
VO_{2max} (ml/kg/min)	42.3 ± 9.3	$44.9 \pm 9.0a$	$39.2 \pm 9.0b$	$43.3 \pm 8.9a$
VO_2 at AT (ml)	1867 ± 704	$2107 \pm 689a$	$1802 \pm 740ab$	$1655 \pm 526a$
RER at AT	0.99 ± 0.1	0.99 ± 0.09	1.0 ± 0.12	0.95 ± 0.08
$METS_{max}$	12.1 ± 2.7	$12.8 \pm 2.6a$	$11.2 \pm 2.6b$	$12.3 \pm 2.5ab$
LT at VO_{2max} (mmol/l)	7.42 ± 5.1	8.02 ± 5.4	7.01 ± 5.1	7.06 ± 4.5
HR at RER1.0 (bpm)	141 ± 18	144 ± 18	139 ± 18	143 ± 20
HR_{max} (bpm)	171 ± 13	$175 \pm 13a$	$166 \pm 13b$	$173 \pm 11ab$

Values reported are means \pm standard deviations. Values with different subscripts are statistically different ($p < 0.05$) by 1-way ANOVA by trial (treadmill v. stand-CE v. sit-CE). Non-standard abbreviations: overall is grand mean for all trials (not used in ANOVA); CE is cycle-ergometry; AT is the so-called anaerobic threshold (a.k.a. first ventilatory-threshold); and LT is lactic acid (lactate).

107.3 ± 33.1), VCO_{2max} (TM = 4.17 ± 0.99 L/min, Stand-CE = 3.62 ± 0.80 , Sit-CE = 3.55 ± 0.83), VO_{2max} (TM = 47.1 ± 9.8 ml/kg/min, Stand-CE = 42.0 ± 9.0 , Sit-CE = 43.3 ± 8.9), $METS_{max}$ (TM = 13.5 ± 2.8 METS,

Stand-CE = 12.0 ± 2.6 , Sit-CE = 12.4 ± 2.5), and HR_{max} (TM = 176 ± 13 bpm, Stand-CE = 171 ± 12 , Sit-CE = 173 ± 11). The highest observed power for all reported variables was < 0.55 for this analysis.

DISCUSSION

The primary purpose of this investigation was to determine if standing while pedaling on a CE, towards the terminal portion of a GXT (Stand-CE), would yield CR values, especially VO_{2max} , equivalent to those obtained per TM-GXT. The results of this study generally do not support the hypothesis that Stand-CE-GXT values are equivalent to TM-GXT values. Table 1 show that crucial TM-GXT CR variables (VCO_{2max} , VO_{2max} , $METS_{max}$ and HR_{max}) were significantly higher than Stand-CE. Likewise, as depicted in Figure 1, VE_{max} , VCO_{2max} , VO_{2max} , $METS_{max}$ and HR_{max} TM values were all significantly higher, per matched-samples T-test, than the Stand-CE values. Although there were no statistical differences on key CR variables between the TM and Stand-CE trials for the 18 participants that completed all three trials (Figure 2), it is likely that this lack of difference between the two trials was due to the relatively low power (the highest power level for all variables for this analysis was < 0.55) of this analysis. The low power was probably attributable to the combination of a relatively small effect and sample size (16). Thus, it appears that TM CR variables are likely to remain larger than Stand-CE values in the general apparently healthy population. To the best of our knowledge, the authors are the first to report these findings using this specific approach to CE-GXT. The finding that TM values are greater than Stand-CE values is similar to previous studies, especially on VO_{2max} , VCO_2 , and RER (2, 3, 8, 18, 29). This pattern (TM $>$ CE) is not without exception. It has been demonstrated that VO_{2max} was independent of mode in young healthy adults (and children) (27). However, it must be noted that mathematically (statistically),

in that study, that the TM- VO_{2max} values were greater than CE- VO_{2max} .

The findings of the current investigation generally demonstrated a lack of statistical difference between the Stand-CE v. Sit-CE trials on crucial CR variables: VCO_{2max} , VO_{2max} , $METS_{max}$ and HR_{max} . That is, standing on the CE towards the end of the GXT did not increase the magnitude of the Stand-CE values over the Sit-CE values. The only exception to this occurred for VO_{2max} (Table 1) where Sit-CE was statistically greater than Stand-CE values. This was an unexpected finding because it was prospectively hypothesized that not only would Stand-CE CR values be equal to TM values, but also that Stand-CE values would be greater in magnitude over Sit-CE values because of greater energy expenditure required to stand and support the trunk of the body along with use of the arms during CE (22). However, consistent with the findings of the present study, *in vitro* testing with a CE demonstrated that there were no differences in VO_{2max} , between standing v. sitting, in competitive cyclists (26). Likewise, in an *in vivo* study, using sub-maximal exercise trials, minor differences in some CR variables (VE and HR) were found between the Sit-CE and Stand-CE trials (22). Similarly, in a study evaluating the effect of seat-position-steepness, in the transition from seated or standing cycling (tri-athletes) to running, found that there was no difference in VO_{2max} (14). Interestingly, inspection of the crucial CR variable data reported in Table 1 and Figure 2 show a non-statistical trend/tendency for the Sit-CE values to be slightly greater in magnitude than the Stand-CE values. The reason for the Sit-CE values to generally be mathematically greater than Sit-CE is not known. However,

the authors suspect that the awkwardness of suddenly standing (being directed to stand by the investigators), while pedaling, might have contributed to the participants prematurely terminating the GXT (Stand-CE test). Alternatively, the reason for the generally lower values for the Stand-CE v. Sit-CE might be that standing at the point when the RER was 1.0 might have been, for many participants, too close to the conclusion of the $\text{VO}_{2\text{max}}$ test to physiologically affect the key CR variables. Further investigation is warranted.

The investigation also evaluated the effect of TM v. Stand-CE v. Sit-CE on other CR variables such as O_2 -pulse, the VO_2 at AT, RER at VT, LT at $\text{VO}_{2\text{max}}$, and HR at RER1.0. With the exception of $\text{VO}_{2\text{max}}$ at AT (Table 1), there were no statistical differences, and essentially no clinical difference between the trials on these variables. In general, the lack of differences per mode of exercise is consistent with previous studies (8, 9). Below are hypotheses for findings of less-discussed CR variables of the present investigation: a. the greater in magnitude VO_2 at AT for the TM and Stand-CE v. the Sit-CE trial (Table 1) might be the effect of doing more work while running on the TM or standing while cycling, b. the reason for HR at RER1.0 to not be different between the two CE trials is that this is the point at which participants stood and pedaled, thus, the two CE trials were identical to that point, therefore, CR values should have been equivalent for the CE trials, and c. the reason for the lack of difference between all trials on LT at $\text{VO}_{2\text{max}}$ and HR at $\text{VO}_{2\text{max}}$ suggests that participants exercised to similar intensities of exercise.

This investigation has some noteworthy limitations. As previously mentioned, some

statistical analyses were weakened by unequal group size in the third trial ($N = 18$, Sit-CE trial v. $N = 34$ in the other two trials). It was regrettable that not all the participants were able or willing to complete all three trials. It was also unfortunate that more volunteers could not be recruited. Increasing group size with a non-homogenous population (age, gender, fitness level, etc.) would have increased the statistical power of the analyses. However, power analysis suggested that a very large number of participants would be required for some variables to achieve ideal power levels (16). Another limitation of the study is that participants were exercised to tolerance. That is, the GXT's were terminated when subjects could no longer keep pace with the TM or their pedaling rate fell below 60 rpm (5). Some participants exercised until a true $\text{VO}_{2\text{max}}$ (plateau of VO_2 , $\text{RER} > 1.15$, lactate > 8 mM) was achieved in some or all of their trials, while other participants simply quit exercising, and thus, achieved a VO_2 -peak in some or all of their trials (13). Having achieved a true $\text{VO}_{2\text{max}}$ in all trials would have strengthened the conclusiveness of the findings. However, when noting the lack of statistical differences between means for the three trials (Table 1), per secondary $\text{VO}_{2\text{max}}$ criteria (RER and LT, and less reliably HR), in general, values are likely to represent being close to or at a true $\text{VO}_{2\text{max}}$ for the trials (11, 13, 27). In further support of participants being close to $\text{VO}_{2\text{max}}$ was that they reached their peak- VO_2 -peak at approximately an ideal GXT time of 10 minutes (8, 20). Another limitation of the study was that a mechanically-braked CE v. an electronically-braked CE was used (24). It would have been more effective to be able to more accurately control the amount of work done per an electronically-braked

CE because as pedaling frequency changes (slowing down or speeding up revolutions/minute) can be compensated for by electronically-modifying the flywheel resistance (19). Likewise, for the TM trial, using a ramping protocol, with small but almost continuous increases in workload, might have influenced CR variables compared with the large increases in work per the stages of the Bruce protocol (2). However, incremental tests (ramping) may not be superior to stage/step tests (13, 23).

In summary, the results of this investigation demonstrate that standing on CE, towards the terminal portion of a VO_{2max} study, did not significantly increase critical CR values to levels typically obtained per a TM in an apparently healthy generalized population. That is, significant differences between TM and CE (whether standing or remaining sitting) on CR variables persisted. Future investigations will be targeted at determining if these findings would be different in specific populations per gender, aerobic training status, in populations that are highly skilled at both cycling and running (e.g. tri-athletes) in young and elderly populations, and in diseased populations (e.g. heart failure, etc.) (5, 6, 14, 17, 28).

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