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Evaluation of the circumplex structure of the Activation Deactivation Adjective Check List before and after a short walk

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Abstract

Background and purpose: The Activation Deactivation Adjective Check List (AD ACL; Thayer, 1989, *The biopsychology of mood and arousal*. New York: Oxford University Press) has been used in several studies to assess affective responses to bouts of physical activity. In recent years, researchers have suggested that the structure of this multidimensional measure should approximate a circumplex. This hypothesis was examined using a circumplex-specific confirmatory method.

Methods: Volunteers ($n = 165$) completed the AD ACL before and after a short walk. The data were analyzed using Browne's Circumplex models for correlation matrices. (*Psychometrika, 57*, 469–497) circular stochastic process model and CIRCUM software and the analyses were performed at the item level.

Results and conclusions: Before the walk, the circumplex provided a close fit to the data, whereas, after the walk, the fit was lower, but still reasonable. At neither time did items theorized to belong to one subscale become interspersed with items theorized to belong to an adjacent subscale. The AD ACL represents a satisfactory, albeit imperfect, option for the assessment of affective responses to physical activity from a circumplex perspective. In the future, closer fit to circumplex structure should be achieved by taking the specific structural postulates of the circumplex model into account from the beginning of the scale development process.

Keywords: Activation Deactivation Adjective Check List; Activation; Valence; Affect; Circumplex

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Introduction

The Activation Deactivation Adjective Check List (AD ACL; Thayer, 1989) has been used in several studies examining affective responses to bouts of physical activity during the past 20 years (e.g. Bird, 1981; Ekkekakis, Hall, & Petruzzello, 1999; Ekkekakis, Hall, Van Landuyt, & Petruzzello, 2000; Hall, Ekkekakis, & Petruzzello, 2002; Jerome et al., 2002; Oweis & Spinks, 2001; Saklofske, Blomme, & Kelly, 1992; Tate & Petruzzello, 1995; Thayer, 1987a,b; Thayer, Peters, Takahashi, & Birkhead-Flight, 1993; Van Landuyt, Ekkekakis, Hall, & Petruzzello, 2000). Yet, as is the case with many of the self-report instruments used in this area of research, the structure of this multidimensional measure in the particular domain of physical activity has not been investigated. The necessity of such investigations was underscored recently, following suggestions from both general psychology (Feldman Barrett & Russell, 1999; Russell & Feldman Barrett, 1999; Schimmack & Reisenzein, 2002; Yik, Russell, & Feldman Barrett, 1999) and exercise psychology (Ekkekakis et al., 2000; Ekkekakis & Petruzzello, 2002; Hall et al., 2002; Van Landuyt et al., 2000) that the structure of the AD ACL should conform to the affect circumplex described by Russell (1978, 1980) and Tellegen and his associates (Tellegen, 1985; Watson & Tellegen, 1985; Zevon & Tellegen, 1982). On the basis of several considerations derived from an analysis of what was termed the 'affect measurement conundrum' in exercise psychology, Ekkekakis and Petruzzello (2002) proposed that the circumplex model could provide a useful conceptual and measurement framework for investigating affective responses to acute exercise. They further noted that the AD ACL, although not originally designed and validated as a measure of the circumplex dimensions, could be used in this role. Given the paucity of multi-item instruments specifically designed as measures of the circumplex dimensions in the literature, an empirical evaluation of the degree to which the structure of the AD ACL approximates a circumplex is important to investigators interested in assessing affective responses to exercise from a circumplex perspective. Thus, the purpose of the present study was to evaluate whether a circumplex provides an adequate fit to AD ACL data collected before and after a short bout of walking by taking advantage of a recently developed, circumplex-specific statistical modeling method (Browne, 1992) and software (Browne, 1995).

The evolution of the conceptual framework of the AD ACL

The AD ACL has been used in conjunction with a variety of conceptual frameworks since its inception. It is, therefore, important to review the history of the measure and explain how a measure that was initially intended to assess the levels of an 'activation continuum' came to be viewed as a potentially useful measure of the dimensions of the circumplex model of affect.

The AD ACL was initially developed as a measure of a bipolar activation continuum ranging from extreme excitement to deep sleep (Thayer, 1967). An item intercorrelation matrix containing 28 items considered to be indices of activation and 21 items considered to be 'nonactivation mood-descriptive' items, derived from Nowlis' (1965) mood measure, was factor-analyzed using the centroid method of extraction followed by a varimax rotation. Four of the 16 factors that emerged 'loaded mainly with activation adjectives' (Thayer, 1967, p. 665). These four factors were labeled 'General Activation' (*lively*, *active*, *full-of-pep*, *energetic*, *peppy*, *vigorous*, *activated*), 'High Activation' (*clutched-up*, *jittery*, *stirred-up*, *fearful*, *intense*), 'General Deactivation' (*at-rest*, *still*, *leisurely*, *quiescent*, *quiet*, *calm*, *placid*), and 'Deactivation-Sleep' (*sleepy*, *tired*, *drowsy*). Thayer's (1967) initial interpretation of these factors was that they 'roughly approximate four points on a hypothetical activation continuum' (p. 668). Consequently, one of the first applications of the AD ACL attempted to demonstrate the advantages of this instrument over the Manifest Anxiety Scale (Taylor, 1953) as a measure of drive (Thayer & Cox, 1968), and subsequent applications focused on demonstrating relationships between the AD ACL and composites of psychophysiological indices of activation (Thayer, 1970, 1971).

As early as 1970, however, Thayer started reassessing his belief in a single activation continuum. This led to the formulation of a model consisting of two bipolar activation dimensions. Dimension A was characterized by energy-sleep and Dimension B was characterized by tension-placidity (Thayer, 1978a, 1985). The relationship between these two dimensions was theorized to vary as a function of one's position along a continuum of energy expenditure. Thus, at high levels of energy expenditure, when the individual is experiencing high tension or high energy, the relationship between Dimensions A and B is theorized to be negative (i.e. *increases* in energy are associated with *decreases* in tension and vice versa). Conversely, at moderate and low levels of energy expenditure, the relationship between the two dimensions is theorized to be either close to zero or positive (i.e. energy and tension *increase* and *decrease* concurrently). This complex pattern of relationships led Thayer to propose that, although the model is mainly defined by the two bipolar activation dimensions, four separate unipolar factors, representing the two high and the two low poles of Dimensions A and B, may also be identified.

This revision of theoretical assumptions led to further investigation of the structure of the AD ACL (Thayer, 1978b), with exploration in two new directions. First, oblique instead of orthogonal rotations were selected, to account for the hypothesized possible relationships between factors. Second, a second-order factor analysis was conducted to examine whether the four first-order factors could be organized into two bipolar higher-order dimensions. The results of this analysis were consistent with the theoretical postulates. Specifically, General Activation and Deactivation-Sleep were negatively correlated (–0.49) as were High Activation and General Deactivation (–0.41). The second-order factor analysis showed that General Activation and Deactivation-Sleep loaded on one bipolar factor (with loadings of 0.74 and –0.63, respectively), whereas High Activation and General Deactivation formed another bipolar factor (with loadings of 0.65 and –0.55, respectively). A revised version of the AD ACL was thus developed by applying the same factor-analytic procedures to a sample of 20 adjectives (five from each first-order factor). With the exception of the items *calm* and *at-rest* which loaded on both the General Deactivation and the High Activation factor (in opposite directions), the resultant four-factor solution exhibited fairly simple structure. The correlation between General Activation and Deactivation-Sleep was –0.58 and the correlation between High Activation and General Deactivation was –0.50. The other factor intercorrelations were lower, ranging between –0.22 and 0.36. A second-order factor analysis showed that General Activation and Deactivation-Sleep formed one bipolar factor (with loadings of 0.76 and –0.73, respectively), whereas High Activation and General Deactivation formed another bipolar factor (with loadings of –0.68 and 0.69, respectively). Additional evidence for the structural validity of the AD ACL was provided in 1986 (Thayer, 1986).

A change in the terminology used to describe the components of the AD ACL was proposed in the late 1980s (Thayer, 1989). Specifically, Dimension A was renamed 'Energetic Arousal'

(EA) and its two opposite poles were named Energy (formerly General Activation) and Tiredness (formerly Deactivation-Sleep). Dimension B was renamed Tense Arousal (TA) and its two opposite poles were renamed Tension (formerly High Activation) and Calmness (formerly General Deactivation). The new terminology will be used in the remainder of this article.

Although arousal formed the core of Thayer's theoretical model, the implications of the model clearly extend beyond the domain of arousal. In fact, Thayer considered arousal a basic element of mood and behavior in general. Thus, the AD ACL has commonly been used as a measure of mood in recent years. This was justified by Thayer's observation that each pole of the two activation dimensions of his model are usually charged with either positive or negative 'hedonic tone' (otherwise referred to as affective valence or pleasure–displeasure). Specifically, Energy and Calmness are typically associated with positive hedonic tone, whereas Tension and Tiredness are typically associated with negative hedonic tone.

Following these observations, it became clear that the bipolar dimensions of EA and TA were essentially compatible with two-dimensional models originally developed to describe affect and mood, such as Russell's (1978, 1980) affect circumplex and Tellegen and coworkers' two-dimensional model of mood (Tellegen, 1985; Watson & Tellegen, 1985; Zevon & Tellegen, 1982). According to Thayer (1989), although the dimensions derived by other investigators have been labeled differently, 'the dimensions themselves are descriptively very similar to Energetic and Tense Arousal' (p. 61; also see pp. 133–134, 164). As noted earlier, this issue has resurfaced recently, as some authors proposed that the structure of the AD ACL can be represented as an affective circumplex (Feldman Barrett & Russell, 1999; Matthews, Jones, & Chamberlain, 1990; Russell & Feldman Barrett, 1999; Yik et al., 1999).

Circumplex models posit that affective states are systematically interrelated and their relationships can be parsimoniously modeled by as few as two basic dimensions (see Larsen & Diener, 1992, for a review). These dimensions are theorized to be orthogonal and bipolar. The relationships among affective states can, therefore, be represented as a circle, with experientially similar states being close together on the perimeter of the circle and experientially antithetical states being located across from each other. Although there is some consensus on these basic postulates, there continues to be disagreement on a number of fronts. Perhaps the most controversial issue involves the determination of the most conceptually appropriate rotation of this two-dimensional system (note that any rotation is defensible from a *statistical* standpoint). Russell and his associates (Feldman Barrett & Russell, 1999; Russell, 1978, 1980, 1989, 1997; Russell & Feldman Barrett, 1999) have supported an *unrotated* version, with one dimension representing affective valence (pleasure versus displeasure) and the other representing activation (low versus high). Tellegen, Watson, and their associates (Tellegen, 1985; Watson & Clark, 1997; Watson & Tellegen, 1985; Watson, Wiese, Vaidya, & Tellegen, 1999; Zevon & Tellegen, 1982), on the other hand, have argued in favor of a 45° rotation of this dimensional system. This results in two bipolar and orthogonal dimensions that combine valence and activation. Specifically, one dimension, labeled Positive Activation (PA; formerly Positive Affect) ranges from activated pleasant affect to unactivated unpleasant affect. The other, labeled Negative Activation (NA; formerly Negative Affect) ranges from activated unpleasant affect to unactivated pleasant affect (for a more detailed explanation and elaboration, see Ekkekakis & Petruzzello, 2001, pp. 213–221).

From a conceptual standpoint, the dimensions of EA and TA in Thayer's model and the dimensions of PA and NA in Tellegen and Watson's model are compatible (Thayer, 1989;

Watson et al., 1999; Yik et al., 1999). Therefore, the AD ACL should be expected to conform to the two-dimensional PA-NA model described by Watson and Tellegen (1985; also see Tellegen, 1985). Initial factor-analytic data presented by Watson and Tellegen (1985) were consistent with this idea. Moreover, Nemanick and Munz (1994) have suggested that the AD ACL may provide a more complete assessment of the theoretical space defined by PA and NA, compared to the Positive and Negative Affect Schedule (PANAS), which is the measure of PA and NA developed by Watson, Clark, and Tellegen (1988). This is because, as others have pointed out (Egloff, 1998; Larsen & Diener, 1992; Mossholder, Kemery, Harris, Armenakis, & McGrath, 1994), the PA and NA scales of the PANAS only assess the high-activation poles of the theoretically bipolar PA and NA dimensions, thus covering only one half of the PA–NA space (see Watson & Clark, 1997, for a response).

Browne's (1992) stochastic process model for the circumplex

Although rudimentary analyses, based mainly on simple correlations and factor analyses, support the validity of the AD ACL as a measure of the two-dimensional affective space, these methods of analysis have been criticized on several grounds (Fabrigar, Visser, & Browne, 1997; Sjöberg, Svensson, & Persson, 1979; van Schuur & Kiers, 1994). Browne (1992) has proposed a solution based on a non-standard covariance structure model developed specifically for the circumplex (see Gurtman & Pincus, 2003; Tracey, 2000, for overviews of circumplex-specific methodologies). This model postulates that the pattern of correlations among variables can be represented as an ordering of the variables along the circumference of a circle. The model assumes that (a) the variance in observed scores on each measured variable is composed of common (among two or more variables) and unique variance, the latter likely to be due in part to measurement error, (b) the circumplex pattern of correlations refers to the correlations among common rather than observed scores, (c) common scores can be represented as points along the circumference of a circle, and (d) the correlation between two common score variables should be a function of the angle between the common score variables on the perimeter of the circle (Browne, 1992; Fabrigar et al., 1997). For example, in the theoretical case of error-free data, the angle of separation between two common score variables correlated at 0.707 would be 45° (i.e. a value estimated by the inverse cosine of 0.707). This can be represented as a Fourier series correlation function (Browne, 1992). It should be clear that empirical data may define an infinite number of possible correlation functions and that the vast majority of them will deviate from a perfect circumplex pattern. The range of possible correlation functions increases as one specifies more free parameters (correlation function weights) in the correlation function equation. Within certain constraints imposed to ensure that the solution will make conceptual sense (see Fabrigar et al., 1997, for a review), the model determines the one solution that best fits the observed data.

Although the mathematical aspects of the model were presented in the early 1990s (Browne, 1992), applications did not start to emerge until a computer program, named CIRCUM (Browne, 1995), was developed as an extension of another program, named AUFIT (Browne & Du Toit, 1992), which was designed for testing non-standard covariance structure models. CIRCUM yields indices of the goodness of fit of the model to observed data (using the Pearson product-moment item inter-correlation matrix as input). Following the postulates of Browne's stochastic process model described above, the goodness of fit indices represent a measure of the extent to which the structure of the data is consistent with a model in which correlations among variables are a function of distance (angle) on the perimeter of a circle. The indices of fit provided by the program include the χ^2 and Steiger's (1990) root mean square error of approximation (RMSEA), a measure of 'badness of fit' or, more specifically, a 'measure of discrepancy per degree of freedom' (Browne & Cudeck, 1992, p. 238). Note, however, that 'there is nothing about the model that limits the researchers to use these indices—nearly any index of model fit used for more standard covariance structure models could be used to assess the fit of the circular stochastic process model with a Fourier series correlation function' (Fabrigar et al., 1997, p. 195). In the present study, we based our interpretation on the RMSEA because of the well-documented advantages of this index, namely insensitivity to sample size and model complexity, robustness to non-normality, and sensitivity to model misspecification (Fan, Thompson, & Wang, 1999; Fan & Wang, 1998; Hutchinson & Olmos, 1998; Olsson, Foss, Troye, & Howell, 2000; Olsson, Troye, & Howell, 1999; Sugawara & MacCallum, 1993). Following Browne and Cudeck (1992), a RMSEA value of about 0.05 or less is interpreted as indicative of *close fit* of the model in relation to the degrees of freedom, whereas a value of about 0.08 or less is interpreted as indicative of *reasonable fit*. Supporting evidence for these interpretations has been provided by the Monte Carlo study of Hu and Bentler (1999), who characterized a RMSEA value 'close to 0.06' as indicative of 'relatively good fit'.

Furthermore, CIRCUM yields several additional useful parameter estimates, including the polar angles of common score variables (i.e. location on the circle in relation to a reference variable, whose position is set to 0°), estimates of the communality of each measured variable (i.e. the proportion of variance estimated to represent common variance), and the minimum common score correlation (i.e. the correlation between variables that are 180° apart). Confidence intervals for these estimates are also provided.

To date, only one study has used the CIRCUM to test the hypothesis that the circumplex can fit data collected with the AD ACL. Yik et al. (1999) reported that the angular locations of the Energy, Tension, Tiredness, and Calmness factors were 56° (49° to 62°), 136° (130–143°), 238° (231–245°), and 302° (296–308°), respectively (the estimates in parentheses represent the limits of the confidence intervals). These locations were relative to the location of an external variable, *Pleasure*, whose location was set to 0°. However, it should be noted that the model examined by Yik et al. included, in addition to the AD ACL scales, several other variables that were also theorized to fit within the circumplex structure, so the overall indices of goodness of fit reported by Yik et al. are not informative of the degree to which the structure of the AD ACL alone conforms to a circumplex. Furthermore, this analysis was done at the level of scale scores, not at the level of individual items, and the observed AD ACL scores that were used to derive the input correlation matrix were based on a composite of response formats and not on the standard AD ACL response format.

Thus, the purpose of the present study was to evaluate the fit of the circumplex, as specified in Browne's stochastic process model, to AD ACL data collected before and after a short bout of walking at a self-selected pace. Previous studies using a similar stimulus have shown significant changes in AD ACL scale scores from before to after the activity (e.g. Ekkekakis et al., 2000; Saklofske et al., 1992; Thayer, 1987a,b; Thayer et al., 1993). It was of interest, therefore, to examine the structure of the AD ACL both before and after the bout of walking.

Methods

Participants

Undergraduate students volunteered to participate (n=165). The sample consisted of 85 women, 75 men, and five individuals who did not indicate their gender. The mean age of the participants was 20 years (range 18–22). They were recruited from their classes at a large university in the USA. The data were collected as part of a class demonstration, but at the time of the data collection, the students were not aware of the exact purpose of this activity. All gave informed consent prior to their participation. No incentive or compensation, monetary or otherwise, was provided.

Measure

The 20-item form of the AD ACL (Thayer, 1989) was used. This form contains five items in each of the four subscales (i.e. Energy, Tiredness, Tension, Calmness). Each item is accompanied by a four-point rating scale (i.e. 'vv' to signify 'definitely feel'; 'v' to signify 'feel slightly'; '?' to signify 'cannot decide'; 'no' to signify 'definitely do not feel'). This scale is then scored from 1 ('Definitely Do Not Feel') to 4 ('Definitely Feel'). The standard instructions recommended by Thayer (1989) were used.

Procedure

The AD ACL was completed in a classroom twice, once before and once immediately after a 10-min walk outdoors, in fair weather conditions. The participants, in groups of about 30, were first given a general introduction to the scale and were then allowed to read the instructions and ask questions. Once all necessary clarifications were given, the participants were asked to complete the AD ACL for the first time. Then, they were asked to walk along a predetermined path on campus at their own pace and return to the classroom. As planned, the participants took an average of 10 min (with a range from 9 to 12 min) to return. A second AD ACL was completed upon their return.

Analysis

The 20×20 item Pearson product-moment intercorrelation matrices from before and after the walk were entered in CIRCUM for analysis. The item *active* (i.e. the first item on the AD ACL) was designated as the reference variable for both data sets. This means that its location was set to 0° and the locations of the other variables were estimated relative to it. This is an arbitrary decision that has no influence on the substantive outcome of the analysis, but it must be taken into account when interpreting the resultant angular locations. No constraints were placed on the location of the variables, the communalities, or the minimum common score correlation (CIRCUM allows these additional constraints to be placed on the model, but they are not necessary for a circumplex). The maximum likelihood (ML) method of estimation was used to fit the model. The fit was examined by consecutively freeing 1 to 10 parameters (correlation function weights in Fourier series) and retaining the solution with the fewer free parameters, beyond which there was no further improvement in model fit.

Results

Scale score changes from before to after the walk

The changes in Energy, Tiredness, Tension, and Calmness scores from before to after the walk were examined, to allow linkages to previously published studies. The physical activity was of low intensity (91 beats·min^{-1}, approximately 15% of age-predicted heart rate reserve, Rating of Perceived Exertion of 10.2, or between 'Very Light' and 'Fairly Light'). All four scales of the AD ACL exhibited satisfactory internal consistency. Specifically, Cronbach's α coefficients were 0.90, 0.91, 0.83, and 0.76 before the walk and 0.88, 0.89, 0.76, and 0.70 after the walk for Energy, Tiredness, Tension, and Calmness, respectively. A repeated-measures (pre, post) multivariate analysis of variance with all four scales as dependent variables was significant ($F(4, 155)=65.09$, Wilks' $\lambda=0.373$, $p<0.001$, $\eta^2=0.627$). Of the univariate tests, the analyses of variance showed (a) a significant *increase* in Energy ($F(1, 158)=230.66$, $p<0.001$, $\eta^2=0.593$); (b) a significant *decrease* in Tiredness ($F(1, 158)=165.66$, $p<0.001$, $\eta^2=0.512$), (c) no significant change in Tension ($F(1, 158)=1.40$, $p=0.238$, $\eta^2=0.009$), and (d) a significant *decrease* in calmness ($F(1, 158)=62.32$, $p<0.001$, $\eta^2=0.283$). In general, this pattern of changes is consistent with findings of previous studies in which the post-activity assessment was conducted as soon as the activity was terminated (i.e. before any recovery or cool-down period).

CIRCUM analysis before the walk

The examination of indices of multivariate and univariate normality did not indicate severe non-normality. Specifically, the normalized estimate of Mardia's (1970) coefficient of multivariate normality was 11.56. Of the 20 items, 16 exhibited univariate skewness and kurtosis values of ±1.0 and 19 exhibited values ±1.5. The exception was the item 'fearful,' which had skewness of 2.0 and kurtosis of 3.2.

The fit of the CIRCUM model continued to improve until nine parameters were freed, but the improvement was minimal after the third. Therefore, to maintain a parsimonious solution, the model with three free parameters was retained. This analysis converged (residual cosine<0.0001) after 23 iterations, with no boundary parameters (also known as Heywood cases, in CIRCUM these anomalies could be either an estimate of unique variance equal to 0 or an estimate of communality equal to 1; see Browne, 1992, p. 472).

The χ^2 (148) was 188.61, $p=0.013$. The RMSEA was 0.041 (90% confidence interval: 0.020–0.057), indicating a close fit. All ratios of reproduced variances to input variances were fairly close to 1, ranging from 0.89 (*wide-awake*) to 1.085 (*tense*). The estimated polar angles are represented graphically in Fig. 1a and their point estimates and 95% confidence intervals are shown in Table 1. The estimated item communality indices are shown in Table 2. These communality indices represent the correlations between measured and common score variables. Therefore, the

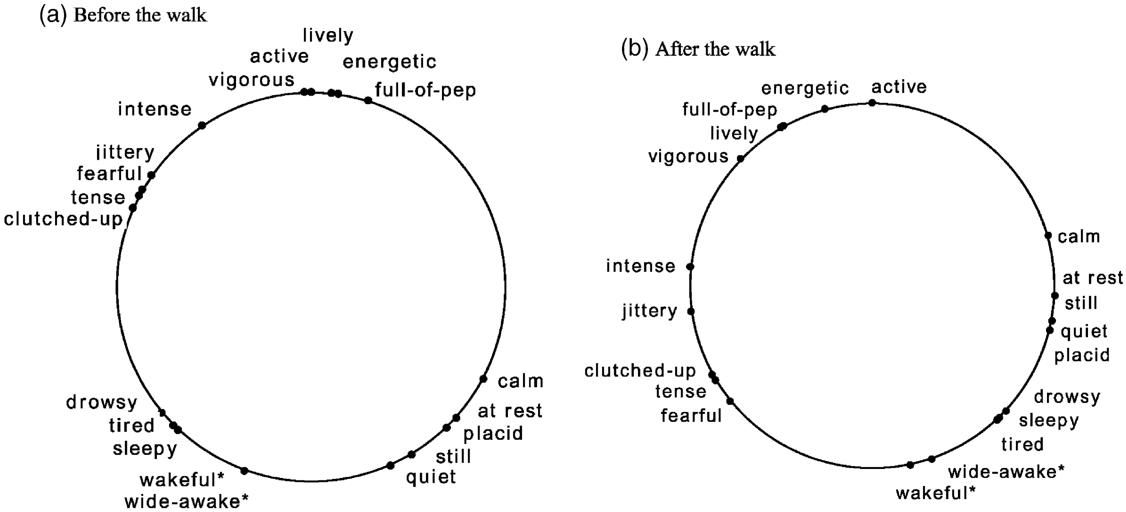

Fig. 1. Polar angle estimates of the AD ACL items before (a) and after the walk (b).

closer these indices are to 1.00, the more common (and less unique) variance is contained in each measured variables. The correlation function estimated by the model is shown in Fig. 2a. The correlation function represents the relationship of the angles of separation between common score variables (Θ) to the correlations between common score variables (ρ). At 180° apart, the common score correlation was estimated at –0.798 and, at 90°, the common score correlation was estimated at 0.03.

CIRCUM analysis after the walk

The estimates of multivariate and univariate normality were very similar to the pre-walk data, so, in general, no indications of severe non-normality were found. Specifically, the normalized estimate of Mardia's coefficient was 11.23. Of the 20 items, 17 had values of univariate skewness and kurtosis ±1.0 and two additional items had values $\pm$ 2.0. The sole exception was again the item 'fearful', with skewness of 2.7 and kurtosis of 7.5.

The fit of the model was improved until a fifth parameter was freed, but the improvement from the fourth to the fifth parameter was negligible. Therefore, the model with four free parameters was retained. This analysis converged after 40 iterations, with no boundary parameters.

The χ^2 (147) was 286.84, $p<0.001$. The RMSEA was 0.076 (90% confidence interval: 0.063 to 0.089), which, while lower compared to the pre-walk data, still indicated a reasonable fit. Several ratios of reproduced variances to input variances deviated somewhat from 1 (*energetic*: 0.863; *active*: 0.879; *full-of-pep*: 0.883; *calm*: 1.155; *at rest*: 1.161). The estimated polar angles are represented graphically in Fig. 1b and their point estimates and 95% confidence intervals are shown in Table 3. The estimated item communality indices are shown in Table 4. The

Table 1
Point estimates (P.E.) and 95% confidence intervals (C.I.) of item polar angles before exercise

Energy	Active	Lively	Energetic	Full-of-pep	Vigorous
Polar angles					
P.E.	0	6	8	17	358
C.I.	(0/0)	(357/16)	(358/18)	(6/27)	(347/8)
Tiredness	Wide-awake[a]	Wakeful[a]	Sleepy	Tired	Drowsy
Polar angles					
P.E.	200	200	223	225	230
C.I.	(189/212)	(188/213)	(211/235)	(213/237)	(217/242)
Tension	Clutched-up	Tense	Fearful	Jittery	Intense
Polar angles					
P.E.	294	298	300	305	326
C.I.	(281/308)	(217/242)	(281/308)	(285/311)	(286/315)
Calmness	Calm	At rest	Placid	Still	Quiet
Polar angles					
P.E.	118	132	136	149	156
C.I.	(103/132)	(118/146)	(120/151)	(136/161)	(142/170)

[a] Item was reverse scored.

Table 2
Point estimates (P.E.) and 95% confidence intervals (C.I.) of item communalities before exercise

Energy	Active	Lively	Energetic	Full-of-pep	Vigorous
Communality					
P.E.	0.67	0.85	0.87	0.84	0.77
C.I.	(0.57/0.76)	(0.79/0.89)	(0.81/0.91)	(0.77/0.89)	(0.69/0.83)
Tiredness	Wide-awake[a]	Wakeful[a]	Sleepy	Tired	Drowsy
Communality					
P.E.	0.80	0.71	0.92	0.92	0.87
C.I.	(0.72/0.86)	(0.61/0.79)	(0.89/0.95)	(0.88/0.95)	(0.81/0.91)
Tension	Clutched-up	Tense	Fearful	Jittery	Intense
Communality					
P.E.	0.79	0.87	0.71	0.73	0.72
C.I.	(0.71/0.85)	(0.80/0.92)	(0.62/0.79)	(0.64/0.80)	(0.62/0.80)
Calmness	Calm	At rest	Placid	Still	Quiet
Communality					
P.E.	0.81	0.76	0.60	0.75	0.59
C.I.	(0.70/0.89)	(0.68/0.84)	(0.49/0.71)	(0.65/0.83)	(0.48/0.71)

[a] Item was reverse scored.

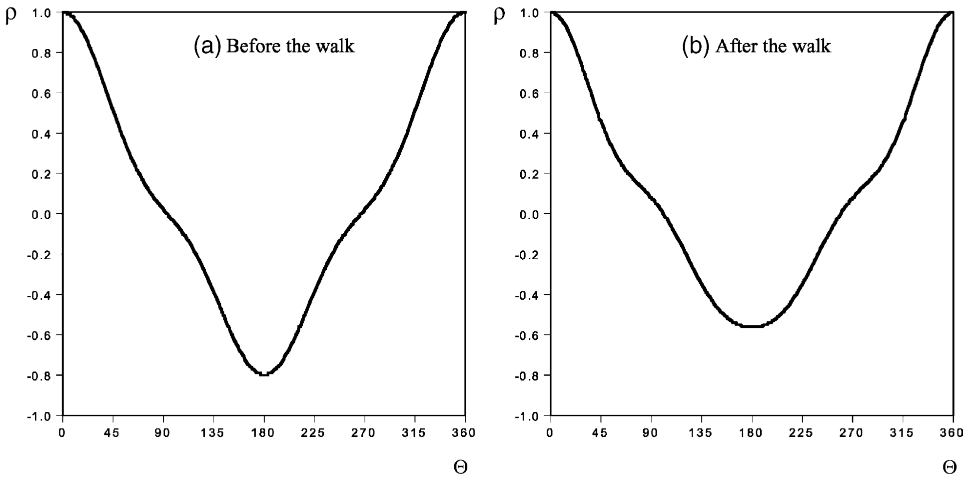

Fig. 2. Correlation functions before (a) and after the walk (b).

correlation function estimated by the model is shown in Fig. 2b. The common score correlation at 180° was estimated at –0.563, whereas the common score correlation at 90° was estimated at 0.07.

Table 3
Point estimates (P.E.) and 95% confidence intervals (C.I.) of item polar angles after exercise

Energy	Active	Lively	Energetic	Full-of-pep	Vigorous
Polar angles					
P.E.	0	330	345	331	314
C.I.	(0/0)	(319/340)	(336/354)	(321/340)	(304/325)
Tiredness	Wide-awake[a]	Wakeful[a]	Sleepy	Tired	Drowsy
Polar angles					
P.E.	161	168	136	137	133
C.I.	(149/173)	(155/180)	(124/149)	(125/149)	(121/146)
Tension	Clutched-up	Tense	Fearful	Jittery	Intense
Polar angles					
P.E.	241	239	231	262	276
C.I.	(228/254)	(226/251)	(217/244)	(247/276)	(264/287)
Calmness	Calm	At rest	Placid	Still	Quiet
Polar angles					
P.E.	74	93	104	101	104
C.I.	(58/90)	(80/107)	(86/121)	(86/115)	(90/119)

[a] Item was reverse scored.

Table 4
Point estimates (P.E.) and 95% confidence intervals (C.I.) of item communalities after exercise

Energy	Active	Lively	Energetic	Full-of-pep	Vigorous
Communality					
P.E.	0.83	0.74	0.86	0.81	0.82
C.I.	(0.70/0.92)	(0.66/0.82)	(0.79/0.91)	(0.74/0.87)	(0.72/0.89)
Tiredness	Wide-awake[a]	Wakeful[a]	Sleepy	Tired	Drowsy
Communality					
P.E.	0.90	0.84	0.76	0.85	0.80
C.I.	(0.81/0.95)	(0.73/0.91)	(0.67/0.83)	(0.78/0.90)	(0.72/0.86)
Tension	Clutched-up	Tense	Fearful	Jittery	Intense
Communality					
P.E.	0.82	0.84	0.78	0.61	0.82
C.I.	(0.75/0.88)	(0.77/0.90)	(0.69/0.86)	(0.50/0.72)	(0.68/0.91)
Calmness	Calm	At rest	Placid	Still	Quiet
Communality					
P.E.	0.83	0.77	0.46	0.63	0.62
C.I.	(0.65/0.93)	(0.67/0.85)	(0.33/0.60)	(0.52/0.74)	(0.51/0.73)

[a] Item was reverse scored.

Discussion

The results indicated that a circumplex had a close fit to the AD ACL data at rest and a reasonable fit after a 10-min walk. Importantly, there were also no cases of item cross-overs (i.e. interspersing of items theorized to belong to adjacent 'sectors' or subscales of the AD ACL). On the other hand, the angles separating adjacent clusters of items occasionally deviated from 90°. Specifically, (i) the Energy items, hypothesized to cluster around 0° (given the fixed location of the item *active* at 0°), had an average estimated polar angle of 6°, with a spread from 358° to 17°; (ii) the Tiredness items, hypothesized to cluster around 180°, had an average estimated polar angle of 216°, with a spread from 200° to 230°; (iii) the Tension items, hypothesized to cluster around 270°, had an average estimated polar angle of 305°, with a spread from 294° to 326°; and (iv) the Calmness items, hypothesized to cluster around 90°, had an average estimated polar angle of 138°, with a spread from 118° to 156°.

After the walk, the fit of the circumplex to the data was somewhat reduced compared to the pre-walk data. Among the residual correlations, 49.5% were >0.10 and 31.6% were >0.15 (compared to only 26.8% and 10.0%, respectively, before the walk). Likewise, several ratios of reproduced variances to input variances deviated from 1.00 and several communality indices were relatively low (e.g. *quiet*, *still, placid*, *jittery*), indicating a certain amount of measurement error. There are at least three possible reasons behind the low communalities:

(a) the first, related mainly to the item '*placid,*' which had low communalities both before and after the walk, is that many respondents might be unfamiliar with its meaning;

(b) secondly, certain items, particularly those with high communalities in one situation and low in another, might become irrelevant to the affective state that many individuals experience after the walk; and
(c) thirdly, as will be discussed further below, some items might be inherently ambiguous and, therefore, their interpretation might change after the walk.

Furthermore, there were differences in the configuration of the items compared to the data obtained before the walk. The most notable such difference was a loosening of the relationships among items theorized to belong to the same scale. Specifically, the range of polar angles was 46° for the items in the Energy scale, 35° for the items in the Tiredness scale, 45° for the items in the Tension scale, and 30° for the items in the Calmness scale (compared to 19°, 30°, 32°, and 38°, respectively, before the walk). Thus, although there were again no cross-overs, the average arc spanned by the items in each of the four scales was extended from approximately 30° before the walk to approximately 39° after the walk.

In interpreting these findings, researchers should take into account the following potential limitations of the present study. First, the sample size was arguably small, a fact that might limit the accuracy of parameters and indices of fit. It is worth pointing out, however, that recent Monte Carlo simulation studies that have tested mildly and moderately misspecified models (as opposed to true models, which are never encountered in practice and are, therefore, mainly of academic significance) have shown that the combination of ML estimation and the RMSEA index of model fit exhibits surprising robustness to variations in sample size and seems to perform well with sample sizes close to 200, such as the one employed here (Fan & Wang, 1998; Fan et al., 1999; Olsson et al., 1999, 2000). Second, the sample of the present study consisted of young college students. Therefore, it would be imprudent to assume that the results will be similar in samples with different demographic characteristics, including health, habitual physical activity, and level of education. Third, concerns have repeatedly been expressed about the properties of the somewhat unusual response scale used in AD ACL. In particular, Meddis (1972) and Cruickshank (1984) questioned whether the response scale maintains ordinal properties, since some respondents might endorse '?' not to indicate a strength of experience between 'feel slightly' and 'definitely do not feel' but rather the lack of understanding of the meaning of a particular word or the irrelevance of an item to their present affective state. Although this remains a valid concern, it should be noted that (a) when Thayer (1986) performed a series of exploratory factor analyses of the AD ACL using three different types of response scales, including the original and two that did not include the 'cannot decide' category, the type of response scale did not influence the emergent factor structure in any substantive way; (b) in the present study, there were no signs of bimodal distributions; and (c) as long as the response scale maintains ordinal properties and the ordered categorical data are not *extremely* non-normal, Monte Carlo studies indicate that ML estimation is fairly robust (Hutchinson & Olmos, 1998). Fourth, the present study did not include a control group. Therefore, even though the scale score changes appear to mirror those reported in other studies that used a similar physical activity stimulus (Ekkekakis et al., 2000; Saklofske et al., 1992; Thayer, 1987a,b; Thayer et al., 1993), any differences between the fit of the circumplex model to the data obtained before and after the walk cannot be attributed to the walk. Perhaps just as plausibly, such changes could be attributed to the passage of time or reactivity to the repeated administration of the AD ACL. Fifth, although our analyses did not reveal signs of severe non-normality, a certain degree of non-normality was present (as in most applied studies) and it could have affected the results of the covariance structure analyses. In particular, as was pointed out, the problem was primarily with the item 'fearful.' After the walk, this item was kurtotic and skewed. Problems with this item have also been reported by Ekkekakis et al. (1999). In the present study, since our purpose was not to construct or modify a scale but rather to test the AD ACL in its original intact form, we decided to retain the item. With this notable exception, the overall degree of non-normality in the present data sets was not sufficient to raise serious concerns. To provide some perspective, in a recent Monte Carlo study that examined the effects of 'slight' (two thirds of the observed variables had univariate skewness and univariate kurtosis of about ± 1.0) and 'moderate' non-normality (two thirds of the observed variables had univariate skewness of about ± 1.5 and univariate kurtosis between $+3$ and $+4$), Fan and Wang (1998) noted an 'almost complete absence of any obvious adverse effect of data non-normality' (p. 730).

With the aforementioned limitations in mind, the following general conclusions can be drawn from the analyses reported. For researchers interested in measuring affect from a circumplex perspective, the AD ACL seems to offer a satisfactory, albeit imperfect, solution. First, the present findings indicate that there is a potential for departures from circumplex structure after respondents are presented with a stimulus like physical activity that is capable of inducing significant affective changes, although, as noted earlier, whether such departures are causally linked to physical activity *per se* cannot be determined with certainty. In any case, changes in the fit of the circumplex model entail the possibility that the assumption of cross-situational structural invariance could be violated, although the severity of such violations cannot be determined on the basis of the present data (and a formal test of invariance is not within the technical capabilities of CIRCUM at this point).

Second, although, importantly, the AD ACL did not exhibit symptoms of item cross-over (i.e. items theoretically tapping one circumplex quadrant intermingling with the items of an adjacent quadrant), researchers should be aware that (a) the items of the AD ACL are likely to span fairly broad sectors of the circle while possibly leaving other sectors unaccounted, and (b) the angular locations of these items may shift across time or different situations. This behavior is perhaps not unexpected, given the fact that the AD ACL was not developed with the circumplex in mind and, consequently, the location of the items on the circle was not used as an item selection criterion in the course of its development. The evaluation of the circumplexity of the AD ACL under two conditions enables us to make a more general observation on this issue. As some authors have suggested (Carroll, Yik, Russell, & Feldman Barrett, 1999), each adjective describing an affective state has a 'characteristic' location in circumplex space. Our results indicate that a 'soft' rather than a literal interpretation of this proposition might be more realistic; that is, when examined across situations, the structure of a given set of items is likely to exhibit some elasticity. Consequently, an item is unlikely to maintain a constant location on the circle. It is reasonable to assume, however, that some items will be more stable than others. For instance, this may be the case with items that do not allow multiple interpretations with regard to the valence (pleasure–displeasure) or degree of activation that they denote. In the present analysis, before the walk, the item *intense*, theorized to reflect Tension, was marginally closer to *jittery* (the closest Tension item) than it was to *vigorous* (the closest Energy item). After the walk, *intense* and *jittery* came closer together but were separated from the other Tension items (compare Figs. 1a,b). This behavior could be attributed to the possible ambiguity of the items *intense* and *jittery* with regard to the affective positivity or negativity that they denote under different conditions. Future research aiming to refine the measurement of circumplex dimensions should take the issue of cross-situational semantic stability versus ambiguity into account.

Third, although we agree with Nemanick and Munz (1994) that the AD ACL has a potential advantage over the PANAS by assessing not only the high-activation poles of the PA and NA dimensions, but also the low-activation poles, we also concur with Larsen and Diener (1992) that an even more complete and refined assessment of the circumplex requires eight unipolar or four bipolar scales. This should improve the construct validity of self-report instruments as measures of the entire circumplex space and should enhance discriminant validity by allowing assessments in terms of octants as opposed to quadrants.

The preceding issues are some of the points that justify the characterization of the AD ACL as a satisfactory measure of the affect circumplex (particularly given the relative paucity of other relevant multi-item measures), but also an imperfect one. Admittedly, our analysis was not comparative. Nevertheless, one can easily detect problems in other instruments that have been discussed as possible circumplex measures. These measures include (a) Mehrabian and Russell's (1974) Semantic Differential Measures of Emotional State, (b) Mackay, Cox, Burrows, and Lazzerini's (1978) Stress/Arousal Adjective Checklist (SACL; a modification of AD ACL for use with British respondents), and (c) Warr's (1990) measure of well-being. In the Semantic Differential Measures of Emotional State, the *pleasure* factor, in addition to standard exemplars of the pleasure–displeasure dimension (e.g. *happy versus unhappy*), also includes items with significant activation content and questionable bipolarity, such as *relaxed versus bored*. Similarly, the *arousal* scale includes the apparently 'pure' marker item *aroused versus unaroused*, but also includes the item *excited versus calm* which may be bipolar in terms of activation, but would probably seem unilaterally positive to most people in terms of its valence content. In the case of the SACL (Mackay et al., 1978), although its scales were labeled *stress* (supposedly indicative of *hedonic tone*) and *arousal* (supposedly indicative of *wakefulness/drowsiness*), an examination of item content reveals that they in fact constitute mixtures of *hedonic tone* and *arousal* (also see Jacob et al., 1989, on this issue). For instance, the *stress* factor includes items such as *tense*, *worried*, and *apprehensive* on one end (indicative of *unpleasant* high arousal) and *peaceful*, *relaxed*, and *contented* on the other (indicative of *pleasant* low arousal). Likewise, the *arousal* factor includes items like *lively*, *energetic*, and *active* on one end (indicative of *pleasant* high arousal) and *sleepy*, *drowsy*, and *sluggish* on the other (indicative of *unpleasant* low arousal). Finally, Warr's (1990) measure of well-being, which combines an *anxious-contented* and a *depressed-enthusiastic* dimension, has been shown to suffer from cross-loadings (e.g. *contented*, *uneasy*) in principal components analyses (Sevastos, Smith, & Cordery, 1992; Warr, 1990). In confirmatory factor analyses of the two-factor solution for both an orthogonal and a correlated model, Sevastos et al. (1992) showed a poor fit, which was attributed to the aforementioned cross-loadings.

These problems have presumably been the result of two factors, both of which can now be effectively addressed with the advent of appropriate statistical models and software. First, problems stem from the inductive methods employed in the development of the aforementioned instruments, including the AD ACL. In some cases, their circumplex or near-circumplex structure emerged through purely exploratory analyses. In other cases, the item selection criteria were crude (e.g. emphasizing scale orthogonality but disregarding item content and, hence, the location of the items on the circle). Second, the problems are partly a reflection of the lack of awareness of or limited sensitization to the technical idiosyncracies of circumplex structural models. As noted in the introduction to this paper, the traditional factor analytic methods of analysis may be inappropriate for bipolar and circumplex data (e.g. Fabrigar et al., 1997; Sjöberg et al., 1979; van Schuur & Kiers, 1994). Researchers have only recently emphasized the importance of such factors as controlling for measurement error and taking the type of response scale into consideration (Feldman Barrett & Russell, 1998; Green, Goldman, & Salovey, 1993; Russell & Carroll, 1999). With increased awareness and the popularization of sophisticated, circumplex-specific, analytic tools such as the CIRCUM, it is expected that these issues will soon be resolved. In the mean time, researchers interested in assessing affect from a circumplex perspective should consider the AD ACL as a reasonable measurement option but should continue to scrutinize its structure when interpreting their results in this light.

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