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Catecholamine Training Effects from Exercise Programs: A Bridge to Exercise-Temperament Relationships [1]

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Three studies were conducted to test whether a catecholamine training effect results from a long-term aerobic exercise program. Study 1 showed significant increases in urinary adrenaline and noradrenaline following moderate mental stress/challenge for male aerobics subjects after a semester of training. Control groups of nonexercisers and continuously in-condition marathoners showed no comparable pre- to post semester catecholamine increases. Male and female Aerobics subjects were contrasted with nonexercisers across a semester in Study 2; the hypothesis was confirmed that postsemester increases in catecholamines occurred only following an episode of mental challenges/stress, and not following base-rate-rest conditions. Under conditions of more active challenge than in Studies 1 and 2, women subjects in Study 3 provided directional but nonsignificant support for the Study 2 findings. The results are discussed in the context of literature on the relationship of catecholamine availability during challenge/stress to temperament and on the relationship of aerobic training to temperament. At a theoretical level, the question is discussed of increased catecholamine availability being a likely mediator in the exercise program to temperament relationship.

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A considerable body of literature has developed in the last decade showing the impact of long-term aerobic training programs on temperament. Our review of that literature led to the broad hypothesis that a likely mediator in the exercise-temperament relationship is an exercise-induced change in the body's generation of the catecholamines adrenaline and noradrenaline. That broad hypothesis in turn led to the specific hypothesis explored by the research presented in this paper. We predicted and tested whether changes in catecholamine generation in human subjects result from an extensive aerobic exercise program.

Both hypotheses will be explored, but in different ways. The specific hypothesis, that exercise programs change the body's catecholamine generation pattern, derives importance from the central role of the catecholamines for so many aspects of human functioning, and from the fact that a catecholamine "training effect" resulting from any voluntary activity has never been demonstrated in humans. The importance of that hypothesis is enhanced if a convincing case can be made for the general hypothesis that temperament changes resulting from aerobic exercise are mediated (in part) by catecholamine changes. That general hypothesis will be assessed through a discussion of several relevant literatures; it provides an important link between those literatures.

The research literature suggests that aerobic exercise programs reduce emotionality and, further, that reduced emotionality is associated with an increased capacity to generate catecholamines during mental challenge or stress. Together these findings provide a basis for our general hypothesis that aerobic exercise programs may influence temperament by increasing the capacity of the body to generate the catecholamines adrenaline and noradrenaline.

The literature further shows that, in humans, an episode of exercise results in temporarily increased catecholamine levels; while it is hypothetical whether a neurohormonal "training effect," in the form of increased catecholamine capacity, should develop following a long-term program of exercise, there is evidence that forced exercise programs for animals have led to increases in catecholamines that are found even .after days of rest.

EXERCISE- TEMPERAMENT RELATIONSHIPS

Many factors have confounded and weakened the research that examines exercise-temperament relationships. (See Sime, (1984) for a thorough recent review.) People who begin aerobic exercise programs usually make other lifestyle modifications, so that it is not possible to isolate the impact of exercise per se. Change in self-esteem, for example, could result from body image changes following exercise-induced weight loss, from new friendships made while exercising, from sleeping better, from a sense of mastery when training goals are reached, from a reduction in anxiety resulting from training-induced physiological changes, and other factors. To overcome such problems, random assignment into carefully structured control groups is required, but such random assignment has never been accomplished. Perhaps most important, research seldom accounts for expectations that subjects may hold concerning psychological changes that "should" result from regular exercise.

Despite the failure of any single study to overcome these problems, our analysis of the relevant literature is not as bleak as suggested by the recent review by Folkins and Sime (1981), who concluded that "it appears that there is no evidence to support a claim that global changes on temperament tests follow from fitness training." (Earlier, Morgan, 1976, had come to a similar conclusion.)

Since several dimensions of the Sixteen Personality Factor Inventory (16PF; Cattell, 1965) constitute a second-order factor of anxiety or emotionality, it is fortunate that the 16PF appears to be the most frequent dependent measure in this literature. Dienstbier (1984) reviewed those 16PF studies with the strongest designs, finding the following (see also Table I):

Briefly, in a pre- to posttraining design, Buccola and Stone (1975) studied men aged 60 to 79 who were involved in either jogging or cycling programs. Hammer and Wilmore (1973) studied 53 men in a pre- to posttraining assessment following a 10-week jogging program. Jones and Weinhouse (1979) used a pre/post approach to study 7 male and 5 female adults through a I-year training program. Young and Ismail (1976) compared 14 highly fit and 141ess fit middle-aged men following their involvement in a semester-long sports and aerobic program. Jasnoski, Holmes, Solomon, and Aguiar (1981) studied 103 college women before and after a semester-long aerobics program; that study is significantly stronger than the others, owing to a rigorous training program of sufficient length, a large number of subjects, and correlations between temperament change and fitness change that can be compared with the pre post changes.

In Table I, the first three columns represent the three factors that regularly constitute a second-order anxiety factor; the second three factors listed are sometimes also included in that second-order anxiety or emotionality factor (Edwards, 1970). As is apparent from the top three sections of the table, whether correspondence between the 16PF dimensions and an exercise program is based on simple correlations, on correlations between changes in fitness with changes in temperament, or on pre-to-post temperament changes, lower anxiety consistently corresponds with aerobic conditioning; there is much less correspondence between exercise and the 10 other 16PF factors. After a thorough review of that literature, Dienstbier (1984) concluded that when the meaningful second-order

Table I. Relationships Between 16PF and Fitness or Adrenaline Level

	16PF factors															
	Anxiety-relevant scales[a]						16PF other scales[b]									
	C	O	Q4	H	L	Q3	A	B	E	F	G	I	M	N	Q1	Q2
Correlations between fitness level and 16PF measures																
Young & Ismail (1976)	+	+	+	+	+			–					+			
Jasnoski et al. (1981)	.28[c]	.26[c]												.20[c]		
Correlations between changes in fitness level and changes in 16PF																
Hammer & Wilmore (1973)					+									–		
Jasnoski et al. (1981)		.49[e]	.24[c]												.37[d]	
Differences between pre- and posttraining on 16PF																
Jasnoski et al. (1981)		+		+									+			
Buccola & Stone (1975)										–						+
Jones & Weinhouse (1979)			+													
Correlations between adrenaline level (μg/ml) and 16PF measures																
Rauste-von Wright et al. (1981)																
Stress conditions	.11	.44	.51	−.33	.53	−.36										
Stress minus control	.21	.44	.30	−.17	.40	−.23										

[a] Within the secondary factor of anxiety, the three main primary factors are C, emotional stability; O, placid (vs. apprehensive); and Q4, relaxed (vs. tense). Three additional primary factors often included are H, venturesome (vs. shy); L, trusting (vs. suspicious); and Q3, undisciplined (vs. controlled).

[b] Naming only the positively scored side of the bipolar dimension, the 10 remaining factors are A, outgoing; B, intelligent; E, assertive; F, happy-go-lucky; G, conscientious; I, tender-minded; M, imaginative; N, forthright; Q1, experimenting; and Q2, self-sufficient.

[c] $p < .05$

[d] $p < .01$

[e] $p < .001$

dimensions of temperament are considered, consistencies are sufficient to support the conclusion of causality between aerobic exercise programs and the temperament dispositions of reduced anxiety or emotionality.

CATECHOLAMINE-TEMPERAMENT RELATIONSHIPS

Although Americans have been aware of the research (following Schild kraut & Kety, 1967) concerning the relationship of deficits in central nervous system (CNS) noradrenaline with depression, American research has tended to follow the tradition of Cannon (1929), whose work suggests that trait emotionality or anxiety would be identified with high catecholamine levels. For example, Funkenstein (1955) presented a series of studies indicating that chronic noradrenaline levels were higher for paranoids and that noradrenaline increases occurred in normals during episodes of anger, while neuroticism and fear were associated with increased adrenaline. Similarly, the autonomic balance literature (Wenger, 1966) emphasized negative aspects of temperament associated with high levels of sympathetic (SNS) activity. This approach is sufficiently influential so that often American researchers simply accept urinary catecholamines as stress measures.

On the other hand, modern Scandinavian research has shown high short-term revels of catecholamines to be adaptive responses to mental stress and/or challenge (e.g., Frankenhaeuser, 1979). (The shift in emphasis reflects a more sophisticated concept of trait - as a disposition to respond consistently in certain types of situations, rather than as a disposition to respond consistently irrespective of circumstances.) Unlike the exercise-temperament research, this area is characterized by (largely) elegant research.

Two caveats apply: First, although these studies often investigate hypotheses about catecholamines, many of the results summarized here concern adrenaline only; while generally similar noradrenaline results are achieved, they tend to be weaker. (Adrenaline is released largely by the adrenal medula and is distributed throughout the body via blood circulation; adrenaline enhances glucose release and metabolism and stimulates increased heart rate. In humans, noradrenaline is released largely at the synapses of sympathetic neurons, resulting in increased blood pressure and playing a role in increased free fatty acid release and metabolism. Both neurohormones are therefore required for, and released during, energy-demanding activities. While some research suggests that adrenaline is more strongly associated with mental activities and noradrenaline with physical activities, those associations are not exclusive.)

Second, stronger relationships between temperament and/or performance and acute increases in catecholamines are often found for males. (Other data have supported the hypothesis that when both male and female students have similar expectations and values-e.g., engineering students, as studied by Collins and Frankenhaeuser (1978) - the sex differences in the relationship of catecholamine secretion to performance and temperament tend to diminish. (See also Johansson, Collins, & Collins, 1983.)

To cite a few examples from a consistent research series, high catecholamine levels following episodes of stress or challenge, or large catecholamine baseline-to-stress changes, have been found to correlate with better performance in target detection in air traffic controller games in American adults (O'Hanlon & Beatty, 1976), with high "ego strength" or greater “adaptive capacity or stress tolerance” in American medical students, (Roessler, Burch, & Mefferd, 1967), with better teacher-rated social adjustment and emotional stability, higher school satisfaction, and better math test performance in Swedish children (Johansson, Frankenhaeuser, & Magnusson 1973), with lower neuroticism scores and less experience of day-to-day stress in Swedish male college students (Forsman, 1980), and with more trust, less apprehension, and less anxiety (on the 16PF) for Finnish male high school students and lower psychosomatic symptomatology for Finnish male and female high school students (Rauste-von Wright, von Wright, & Frankenhaeuser, 1981). Since this final study used the 16PF, those data are presented in the final row of Table I to emphasize the relationship of this literature to the exercise-temperament area.

Similarly, Dienstbier, LaGuardia, and Wilcox (1987) have shown that :old tolerance (an indicator of adrenergic strength or responsivity) is associated with reduced emotionality, reduced depression, and increased activity and stimulation seeking.

In summary, this (largely) Scandinavian research shows that when individuals have large urinary catecholamine increases (compared to base rates n relaxed conditions) in response to stress, they perform better (on even complex tasks such as mathematics exams) and they are judged by themselves on inventories) and by teachers or peers to be generally calmer and better emotionally adjusted.

ACUTE EFFECTS OF EXERCISE ON CA TECHOLAMINES

Researchers have established that episodes of aerobic exercise as long as marathon running (e.g., Appenzeller & Schade, 1979) or as short as 3 minutes on a bicycle ergometer (e.g., Dulac et al., 1982) are accompanied by acute increases in adrenaline and noradrenaline. Both catecholamines have been shown to correspond to physical work load (Howley, 1976). A major principle of the exercise-physiology area is that when physiological systems are taxed through regular exercise they show increased capacity through a "training effect." While such effects are usually thought of as muscle effects, some have speculated that training effects might occur for the generation of steroids or hormones following the repeated taxing of the ANS and associated adrenal-medullary and adrenal-cortical responses during exercise episodes (e.g., Folkins & Amsterdam, 1977).

TRAINING EFFECTS WITH INFRAHUMANS

Research largely with mice and rats has suggested "training effects" from regular stress or stimulation that sometimes includes exercise. Rats and mice have been handled, shocked, reared by an overly stimulating or emotional parent, or otherwise stimulated or stressed regularly when young; they have been found to develop subsequently into less "emotional" adults than unstimulated controls (e.g., Denenberg, 1967; Levine, 1960). While it cannot be unequivocally concluded that catecholamines or SNS processes mediate those developments in temperament, adrenal gland development typically follows from the stimulation received by the experimental groups (though researchers in the area have typically focused upon adrenal-cortical processes). More recent research has shown noradrenaline increases in the brain of rats who were forced into 8-week running "programs" compared to sedentary controls (even when sacrifice followed the last period of exercise by days (Brown & Van Huss, 1973; Brown et al., 1979)).

The only study (other than ours) investigating similar relationships with humans used a correlational approach (Sinyor, Schwartz, Peronnet, Brisson, & Seraganian, 1983). Newspaper ads recruited 15 exercisers and 15 nonexercisers who were then compared for physiological responses to challenging tasks (e.g., mental math, Stroop task). Trained subjects showed higher blood norepinephrine levels immediately following challenge than did the sedentary controls. However, the problems are obvious for meaningfully interpreting a posttest-only study when subjects are not randomly assigned to conditions. One way of interpreting the findings is that those who chose to become involved in aerobics normally show greater noradrenaline responses (rather than that aerobic activity caused heightened catecholamine responsivity); causal directions cannot be inferred.

STUDY 1

Given the relationship described above between exercise programs and temperament on the one hand and catecholamines and temperament on the other, we hypothesized that a "training effect" for the catecholamines was a likely mediator of the exercise-temperament relationship. In Study 1 of this research series, we attempted to ask only the unelaborated question of whether a catecholamine training effect develops from an exercise program.

But under what circumstances should such a training effect become evident? Four conditions are critical: First, we would not expect to observe the effect following a test period of physical exertion, since the higher catecholamine-generating ability of the physically conditioned individual may be offset by increased physical efficiency, requiring less arousal (e.g., McCrimmon, Cunningham, Rechnitzer, & Griffiths, 1976; Cooksey, Reilly, Brown, Bomze, & Cryer 1978; Peronnet et al., 1981). Second, because of a potentially confounding short-term catecholamine response following an episode of exercise, observation of the training effect must not follow an exercise episode too closely. Third, a catecholamine training effect should result from an aerobics training program of sufficient intensity and duration that obvious improvement in aerobics capability occurs. Fourth, since potentially confounding changes in season and academic stresses will occur for student subjects, control subjects must also participate in the testing activities.

We therefore hypothesized a pre- to postexercise program increase in catecholamine excretion following a short period of mental challenge/stress for subjects who participated in a semester-long aerobic exercise program. In all three studies, subjects did not participate in aerobics on the days of lab activities (prior to testing). In Study 1, the Aerobics condition subjects were contrasted at both time periods with two control groups - sedentary Nonexercising controls, and Marathoners who remained in top aerobic condition during the semester.

Method

Subjects and the Independent Manipulation. In Study 1, only male subjects participated owing to the unavailability of female subjects for the marathoning control group.

Nonexercising control subjects were recruited from the introductory psychology course to fulfill a library or research requirement (other research options were available). We screened at the semester's begining and end to make sure that, as requested, only individuals not involved in systematic aerobic exercise had volunteered. Contrary to instructions, two subjects began their own personal aerobics programs at the beginning of the semester, one averaging 18 miles per week in six 3-miles runs, and the other averaging 9 miles per week in three 3-mile runs. Those two individuals were reclassified as Aerobics subjects when they revealed their running at the semester's end. Of the 16 subjects initially recruited, 2 could not be located at the semester's end. Thus, complete data were available for 12 Nonexercising subjects.

Aerobics condition subjects were all college men who were enrolled in one-semester aerobics running classes and who volunteered for the research. We recruited only novice runners, and screened for running history, excluding those indicating systematic aerobics activities within the previous 6 months. The aerobics classes met and ran three times per week throughout the semester; members were encouraged to run during nonclass times as well. Of the 12 subjects initially enrolled, 3 could not be contacted at the semester's end, and 1 could not supply a urine sample. With the addition of the 2 exercising subjects initially assigned to the Nonexercising control group, we had complete data for 10 Aerobics group individuals. By the semester's end, each student in the aerobics class engaged in a long solitary run as far as his own estimate of capability; all 8 who were in the aerobics classes ran over 12 miles in their final "contract" run.

Marathon group subjects were college men who were experienced runners and who volunteered to participate in our research in exchange for personalized coaching (from R. S.). Their intent was to complete a specific marathon scheduled for the semester's end. All had been running during much of the previous 6 months, most very regularly. Of the 16 subjects initially participating, 2 sustained injury and 1 was unavailable at the semester's end, leaving complete data for 13 subjects; all 13 ran in the scheduled marathon at postsemester.

Design. Three groups of male subjects participated in a semester-long pre post study. The Aerobics subjects constituted the experimental group, since only they experienced change in aerobic fitness across the semester. Subjects reported to our lab prior to any aerobic exercise (on that day) at pre- and at postsemester for a session of moderately challenging and stressful tests. Subjects provided urine samples for later catecholamine analysis following those sessions.

Procedure. To control diurnal rhythm influences, subjects reported at the same time of day in the pre-and postsemester session. They were also asked to refrain from alcohol, tobacco, caffeine, or drugs from 10:00 p.m. of the night before. Compliance with these requests was monitored and was excellent.

After emptying their bladders and drinking a specified amount of water, subjects were seated and connected to physiological monitoring equipment for measurement of galvanic skin response (GSR) and finger pulse volume. After physiological base rates were obtained for 3 minutes, subjects listened through headphones to a 20-minute tape of loud (92-dB) sounds separated by variable intervals averaging 30 seconds. The sound included breaking glass, and automobile crash recorded from a professional sound-effects tape, an often-repeated electric drill, and a circular saw cutting wood, and ended with an announced sequence of a balloon blown up until it burst. Listening to the tape was only mildly stressful as indicated first by most subjects adap ting to the seconds (until the balloon sequence, which stimulated large responses). The second indicator of mild stress was the average sound-tape rating of 4.4 on a scale ranging from "very pleasant" (scored 1) to "very stressful" (at 7). (Subjects rated the tape at postsemester to be nonsignificantly more stressful than at presemester, suggesting that adaptation from hearing the same tape twice was not a factor.)

Following the sound tape, subjects stared at a fixation point in the dark and under conditions of bright light while infrared photographs of their eyes were taken. The task required firmly fixed visual attention for several minutes. Subjects then spent 5 minutes in a temperature-controlled room at 59° F while dressed in pants and shirt, and subsequently completed brief forms including checks on their recent running (for those in the running conditions). Having spent an hour in the lab, subjects contributed a urine sample and departed. Urine samples were immediately acidified at pH 3 and stored frozen for later analysis.

Results

Separated assessments of adrenaline and nonadrenaline were accomplished with the fluorometric technique following ion exchange on resin columns of Bio-Rad Laboratories. Table II indicates those hormone levels by experimental condition at the beginning and end of the semester.

While adrenaline levels were similar at presemester for Nonexercise and Aerobics students, they were considerably higher for the well-conditioned Marathoners. (This finding supports the correlational finding of Sinyor et al., 1983), noted earlier.) At postsemester, while Nonexercisers remained constant, adrenaline levels for the Aerobics subjects almost doubled ($t = 2.37$, $P < .05$, two-tailed), approximating both the pre-and postsemester levels of the Marathoners.

Contrasted with the pre- to postsemester consistency in noradrenaline for Nonexercisers, there is a large and statistically significant increase ($t = 2.75$, $P <$ .01 two-tailed) for the Aerobics subjects, and a smaller increase for the Marathoners. Although the catecholamines of the Aerobics subjects increased significantly across the semester, as predicted, the important two-way (repeated measures) ANOVA interactions for adrenaline and for noradrenaline were not quite statistically significant ($p <.10$ in both cases). (The increase for Marathoners may be related to dietary change, since at postsemester they were beginning to increase their carbohydrate intake in preparation for the coming marathon; noradrenaline excretion increases and adrenaline decreases with increased carbohydrates.) The loss of 20% of the original subjects is another factor that suggests caution in the interpretation of these results.

Table II. Study 1: Urinary Adrenaline and Noradrenaline Levels following Mild Stress at the Semester's Beginning and End (in μg/ml)

	Adrenaline			Noradrenaline		
Time of semester	Nonexercisers $N = 12$	Aerobics $N = 10$	Marathoners $N = 13$	Nonexercisers $N = 12$	Aerobics $N = 10$	Marathoners $N = 13$
Beginning	.52	.77	1.31	3.18	1.90	2.91
End	.66	1.24	.98	3.45	4.54	4.02

Discussion

While these data confirm the hypothesis of posttraining catecholamine increase following stress/challenge, they are not as strong as we would have liked, and they raise other issues.

The first of those issues concerns sex differences, since only males participated in Study 1.

But the most salient issue concerns whether the higher postsemester catecholamines for the Aerobics subjects were due to the challenge and stress of our lab procedures or to higher resting base rate levels.

STUDY 2

Method

Study 2 was undertaken to overcome the limitations of Study 1, with no new hypotheses except that we predicted no between-groups pre-to postsemester differences in resting base rate catecholamine levels.

Subjects and the Independent Manipulation. Except that no Marathoning subjects were recruited, subjects were recruited and defined as in Study 1. While 11 male and 15 female subjects participated initially in the Aerobics group, 16 male and 11 female subjects were in the Nonexercising control group. During the semester, 2 male and 2 female Aerobics subjects dropped out of aerobics or became unavailable; 6 control males were unavailable at postsemester and the data were dropped from a non (native)-English-speaker who was sometimes confused by our procedures. Complete data were obtained and analyzed from 22 Aerobics and 20 Control subjects.

Design. As in Study 1, subjects reported to our lab at pre-and postsemester, before any exercise on that day. In Study 2, however, at both the pre- and postsemester sessions, subjects spent 45 minutes relaxing before the first urine samples were given, and gave second samples following a subsequent 45-minute period of challenge/stress activities. We predicted a significant three-way interaction in the catecholamine measures - an interaction resulting from greater catecholamine availability after the challenge/stress period.

Tasks and Measures. After observing food, drug, and exercise restrictions, subjects arrived at the same time of day and were exposed to identical procedures at pre- and postsemester.

Subjects initially drank 14 ounces of water, emptied their bladders, and filled out consent forms. So that we could obtain a resting base rate catecholamine measure, subjects read our magazines or used only study materials compatible with relaxation. Following that 45-minute period, a urine sample was obtained and subjects again drank 14 ounces of water. They were then connected to a physiograph to monitor GSR and finger pulse volume, and subjected to a sound tape similar to that described for Study 1. Following that 20-minute tape, disconnection from the physiograph, and the filling out of a few brief forms, subjects studied or read until 45 minutes had passed since the previous urine sample. They then contributed a second urine sample and departed.

Results

Although catecholamine analyses were undertaken with the same assay technique briefly described above, we were unable to obtain accurate separate measures of adrenaline and noradrenaline. We used instead a measure of total free (or "unconjugated") catecholamines. Since other products resulting from the breakdown of adrenaline and noradrenaline were present but not assayed, free catecholamine measures do not provied a measure of absolute catecholamine levels in the blood or urine. Without being able to differentiate between the relative amounts of adrenaline and noradrenaline, the measure provides a ratio-scale measure of both catecholamines. Since all comparisons in Studies 2 and 3 are of differences in catecholamine levels between conditions or sessions, knowledge of absolute urinary or blood catecholamine levels is not needed.

The pattern of means in Table III unexpectedly reveals decreases in catecholamines between the resting base rate and the postchallenge/stress period ($F(l, 38) = 50.0$, $p < .001$). This trend is apparently due to a high resting base rate, the high base rate probably being attributable to a variety of factors, from subjects' concerns over arriving on time to our not having more time to acclimate our subjects to the lab at both the pre- and postsemester sessions. Frankenhaeuser (1975) had warned that research subjects often take hours to adapt to laboratory surroundings before giving base rate urinary catecholamine responses; we took insufficient account of her warning. We therefore tested for lower decreases for the postsemester Aerobics subject (compared to Controls) from rest to stress conditions rather than for the increases we had expected.

Our main statistical test was a repeated-measures analysis of the interaction of the three factors of group (Aerobic vs. Control), time of semester (beginning or end), and pre- or postchallenge/stress. Our hypothesis was confirmed by the significant three-way interaction ($F(1, 38) = 4.09$, $p < .05$); the pattern of means clearly supported our hypothesis. As predicted, while Aerobics students showed less of a postrelaxation to poststress catecholamine drop at postsemester

Table III. Study 2: Total Catecholamines Following Rest and Stress Conditions at Semester's Beginning and End (in $\mu g/ml$)

	Aerobics $N = 22$, (9 M, 13 F)			Nonexercisers $N = 20$, (9 M, 11 F)		
Times of semester	Postrelax	Poststress	Difference (R–S)	Postrelax	Poststress	Difference (R–S)
Beginning	4.37	2.30	2.07	3.27	1.93	1.34
End	3.00	1.36	1.64	4.68	1.66	3.02

compared with presemester, Controls showed a greater drop at postsemester than at presemester.

To simplify presentation of that interaction, a difference-score format is used in the third and sixth columns of Table III so that the interaction appears in the simpler format of a two-way interaction of difference scores; as indicated above, however, the data were not analyzed as difference scores. (Two alternatives to our repeated-measures analysis of variance method were considered at the suggestion of a knowledgeable review -analysis of covariance in which the pretest would have been the covariate, or a gain-score analysis. For various reasons, those alternative techniques were not appropriate solutions to the problem of catecholamine- base rate differences between the groups in Study 2. While the analysis we used does not solve that problem, it is the most appropriate approach from the available statistical tools.)

Two data trends are also interesting. First, a nearly significant interaction *(F* (1, 3) = p < .07) between group and time of semester indicates that, across both relaxation and stress conditions, Control subjects had higher catecholamines at postsemester (3.17) than at presemester (2.60), in contrast to Aerobics students, who demonstrated the opposite trend (2.18 at postsemester vs. 3.33 at presemester). This difference is due to higher postrelaxation catecholamines for the Controls at postsemester (contrasted with Aerobics subjects). Second, there is a suggestion *(F* (1, 38) = 2.39, p < .15) of higher catecholamines for males than for females.

The loss of 20070 of the Study 2 subjects from the beginning to the end of the semester again suggests some possible limitations in the generalizability of these results.

STUDY 3

Method

A final study was added to examine the issues of Study 2 with more actively involving stress-challenge tasks than used previously. Hypothesis, design, and procedures were as stated for Study 2, except as noted.

Subjects and the Independent Manipulation. Our recruitment efforts were met with mostly women aerobics students volunteering (so few male volunteered that we used only female subjects for both groups). We recruited 17 Aerobics subjects and 26 Nonexercising controls. During the semester, 3 Nonexercisers and 1 Aerobics subjects became unavailable.

Tasks and Measures. Unlike Studies 1 and 2, in which subjects participated individually, subjects reported to the lab in groups of three to five. Some physiological monitoring was done during the initial relaxation period (in addition to challenge/stress period monitoring). A portable physiograph wheeled from individual to individual measured blood pressure, pulse rate, skin temperature, and GSR.

After contributing their postrelaxation urine samples, subjects were seated in individual booths from which they viewed themselves on a TV monitor and were led to believe that they were being videotaped and individually audiotaped (through a microphone connected to a tape recorder in front of each individual).

The Stroop color-naming task required subjects to name the color in which color words were written while those words moved across a second TV screen. Our version was made more difficult than usual (following a procedure developed by Frankenhaeuser, 1979) by noise and an interfering voice heard through headphones; the voice admonished carefulness and named colors irrelevant to the correct answers. This 10-minute task was paced to be challenging and frustrating.

There followed a discouraging and difficult 10-minute task in which subjects announced the cumulative sum of a series of numbers that appeared rapidly on the TV monitor. Nine such summation sequences were used. Subjects then filled out questionnaires until the 45-minute stress-challenge period ended.

Results

As indicated in Table IV the pattern of the data for total free catecholamines was very similar to the pattern obtained in Study 2, with overall decreases in catecholamines from the end of the relaxation period to the end of the challenge period ($F(I, 37) = 10.2$, $p < .01$), but with the magnitude of that decline greater at presemester than at postsemester for Aerobics students, and with far less differences across the semester for the Controls. The three-way interaction was not statistically significant, however.

Four major changes between Studies 2 and 3 may have contributed to the somewhat weaker findings of Study 3. First, the challenge/stress period used a new set of tasks that required active subjects involvement and the potential for frustration and discouragement. Second, subjects participated in small groups rather than individually. Third, physiological monitoring was undertaken during both the relaxation and challenge phases. Finally, only females participated in Study 3.

Of these four factors, it seems unlikely that the heightened potential for stress is an important factor; a more powerful Study 3 manipulation should have caused even larger catecholamine differences between the two groups. On the other hand, participation in groups may have lowered the stress potential of

Table IV. Study 3: Total Catecholamines Following Rest and Stress Conditions at Semester's Beginning and End (in $\mu g/ml$)

	Aerobics N = 16, all women			Nonexercisers N = 23, all women		
Times of semester	Postrelax	Poststress	Difference (R–S)	Postrelax	Poststress	Difference (R–S)
Beginning	4.38	1.90	2.48	3.82	1.80	2.02
End	3.66	3.28	.38	4.63	3.18	1.45

Study 3, despite our efforts to suggest individual performance monitoring. Additionally, it is possible that, given our subjects' difficulty in acclimating to the laboratory conditions (as suggested by the high "resting base rate" catecholamine levels), the addition o~ our physiological monitoring during the relaxation period may have reduced the ability of our subjects to really relax, resulting in attenuated between-condition differences. Finally, while initially it seemed to us unlikely that using only females would be a crucial problem, since in Study 2 similar catecholamine patterns appeared for both sexes, the Scandinavian research cited earlier has often shown lower catecholamine responsivity in such situations for females, suggesting that sex could also be a factor.

CONCLUSIONS

One of the more vexing results of these studies was the finding, in Study 2, replicated in Study 3, of higher catecholamine excretion in base rate-rest conditions than following the stress/challenge manipulations. Although that finding is understandable for the reasons discussed following Study 2, it raises the question of whether a meaningful test of the main hypothesis is possible.

In response to that question, we are not unique in finding conditions in which many subjects show urinary catecholamine declines across research procedures that (one would think) should stimulate increasing arousal. Johansson et al. (1973) studied sixth-grade children who watched an unexciting 42-minute movie about mining followed by an equally long mathamatics exam in their classroom; a third of the children decreased from postmovie to postexam in urinary adrenaline (with the decreasers making increasingly more errors as the exam progressed, in contrast to the adrenaline increasers). Such findings suggest that one may consider catecholamine decline in circumstances such as ours to be comparable to attenuated increases in circumstances where test conditions more uniformly evoke increases.

The results of Study 1 suggested that aerobic training resulted in increased postsemester catecholamine generation, but it was uncertain whether the challenge/stress of the test circumstances were the immediate cause of that increase, or whether resting base rate levels changed. The Scandinavian research has shown that high acute catecholamine generation in response to specific instances of challenge/stress are adaptive and associated with positive personality characteristics when base rates remain low and the return to base rate levels of urinary catecholamines is rapid (Johansson & Frankenhaeuser, 1973). Our hypotheses for Study 2 were therefore that base rate levels would remain unresponsive to aerobic training. The supportive and significant results of Study 2 and the supportive but nonsignificant data of Study 3 affirm the prediction that resting base rate catecholamine levels do not change with aerobic training, but that challenge/stress conditions do elicit larger catecholamine increases (or lower decreases) in fit individuals. Such catecholamine training effects resulting from exercise programs for humans have not previously been demonstrated.

Exercise- Temperament Relationships

With our main hypothesis confirmed, we address the possible role of catecholamine increase as a mediator of the exercise-temperament relationship. The strongest confirmation of that hypothesis depends first upon establishing causal relationships between the primary independent and dependent variables (exercise programs and temperament). Causal relationships should be established secondly between the independent and mediating variables (exercise programs and catecholamine increases) and thirdly between the mediating and dependent variables (catecholamines and temperament). Additional support is obtained if the relationships fit within a nomothetic network of other supporting data and theory.

Clearly, all of the stringent requirements outlined above have not been met. While the primary question of an exercise-to-temperament link is answered affirmatively here and in Oienstbier's (1984) review, other reviewers do not agree that causality has been satisfactorily established (cf. Folkins & Sime, 1981). Since those relatively conservative conclusions, however, some well-structured studies have been published (e.g., Jasnoski et al., 1981), and the first strong research demonstrating reduced depression associated with aerobic training has appeared (McCann & Holmes (1984). Acceptance of the second causal relationship of exercise program to catecholamine changes depends upon accepting our three studies as sufficient evidence and upon viewing the excellent research by Brown and colleagues with rats as relevant and therefore supportive (reviewed above, Brown & Van Huss, 1973; Brown et al., 1979). Third, only a correlation, not causation, has been established by the Scandinavian research between high catecholamine availability following challenge/stress and temperament. Similar limitations on causal inference apply to the Oienstbier et al. (1987) demonstration of a relationship between adrenergic responsivity, as indicated by tolerance of cold, and reduced emotionality and depression.

Thus, while the confirmation of our specific hypothesis of exercise programs affecting catecholamine patterns lends strength to the hypothesis of catecholamine increases as a mediator in the exercise-temperament relationship, we cannot claim absolute confirmation of this more general hypothesis. But hypotheses at this level are seldom confirmed or disconfirmed in any absolute sense. Insofar as the exercise-temperament hypothesis is credible (albeit not "proven"), we may speculate on possible implications.

Our findings of a catecholamine training effect leads directly to explanations for how exercise programs apparently reduce depression (e.g., McCann & Holmes, 1984). Although our urinary catecholamine measures index peripheral more than CNS catecholamines, recent findings that the catecholamines cross the blood-brain barrier suggest that increasing peripheral catecholamine levels may have effects on CNS availability as well. An impact upon the CNS is also achieved by the glucose-stimulating function of adrenaline, since glucose is the fuel of the nervous system.

Aerobic running may affect emotionality through a physiological path besides the adrenergic responsivity shown by our studies. In aerobic running programs such as represented here, sufficiently long runs are undertaken that episodic heat adaptation is required to control core body temperature. Since temperature tolerance develops over time, with repeated or consistent exposure to thermal environments requiring adaptation, some increase in heat tolerance may develop from running. Given the Dienstbier et al. (1987) findings of primarily cold tolerance (indexing adrenergic responsivity), but secondarily heat tolerance, associated with reduced emotionality, aerobic running (in contrast to cooler exercise such as swimming) may attenuate emotionality through these two mediational paths. Further research will be needed to establish this relationship.

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