Original Article

Cardiovascular Response to Mental Stress Tests and the Prediction of Blood Pressure

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ABSTRACT

Background: It has been proposed that increased physiological responses (i.e., cardiovascular reactivity) to a stressor or stressors may increase the risk of developing cardiovascular disease (CVD) including increased blood pressure (BP) or hypertension. However, many prospective studies have examined the hemodynamic reactions to laboratory stress tests and CVD in Western countries and only a few studies have examined with varying durations of follow-up in the same sample studies. In addition, still relatively little is known about cardiovascular reactivity in Asian populations. Therefore, the aim of this study was to examine whether cardiovascular responses to psychological stressors remained a significant predictor of 40-month follow-up among initially normotensive participants in Thailand, Asia. **Materials and Methods:** Hemodynamic parameter was measured at rest, during, and after mental arithmetic, a speech task, and a cold pressor task. Ninety-five healthy normotensive male and female participants were reevaluated BP at 40 months later. **Results:** Regression analyses indicated that after adjustment for baseline BP, initial age, sex, body mass index, and family history of CVD, heightened systolic BP (SBP) responses to mental arithmetic was associated with increased future SBP ($\Delta R^2 = 0.04$, $P = 0.023$). **Conclusions:** Therefore, these findings suggest that cardiovascular reactivity remains a prediction of future BP and may play a role in the development of hypertension and CVD.

Key words: *Blood pressure, cardiovascular reactivity, hypertension, psychological stress*

INTRODUCTION

Hypertension is the most significant risk factor associated with the prevalence of cardiovascular disease (CVD). It is likely that great many pathophysiologic factors contribute to the elevated blood pressure (BP) in hypertensive patients; these include raised sympathetic nervous system activity. One mechanism linking pathophysiological interrelated factors to high BP is the sympathetic nervous system. There is much evidence to show that an overactive sympathetic nervous system elevates BP and contributes to the development of hypertension status via stimulation of the heart, peripheral vasculature, and kidneys.[1]

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One factor that has been found to increase sympathetic nervous system activity is elevated responsiveness to stressful stimuli. Further, it has been reported that cardiovascular responses to psychological stress tests have been shown to be good predictors of future increases in BP and for hypertension status. The reactivity hypothesis posits that exaggerated hemodynamic responses (i.e., heart rate [HR] and BP) to an aversive challenge, or engaging laboratory-induced stressors predict or contribute to future BP and hypertension.[2-4] Over the past few decades, several studies have indicated that heightened cardiovascular reactions to laboratory stressors may be a risk factor for high BP, hypertension status, and CVD.[2,5] However, many prospective studies have examined the hemodynamic reactions to laboratory stress tests and CVD in Western countries. In addition, only a few studies have examined with varying durations of follow-up in the same sample studies. According to cardiovascular responses to mental stress tests and 1 year follow-up in Thais, it was found that greater systolic BP (SBP) responses to mental arithmetic tasks play a role to predict future BP in normotensive healthy Thai individuals; initial baseline SBP accounted for 16.8% of the variance in follow-up SBP levels and SBP responses to mental arithmetic tasks accounted for an additional 4.5% of the variance even after controlling for age, sex, body mass index (BMI), and family history of CVD.[6] Interestingly, these results accord with findings from the Western countries, for example, in the United Kingdom study, SBP responses to mental arithmetic were predictive of follow-up SBP levels; initial baseline SBP accounted for 28.9% of the variance in follow-up SBP levels. After statistical adjustment for traditional risk factors and baseline cardiovascular activity, SBP responses to mental arithmetic explained 4.7% of the variation of future SBP levels.[7] Thus, SBP responses predicted a similar proportion of the variance in future SBP independently of initial resting SBP and traditional risk factors in Western and Asian studies. It was worthwhile to reexamine whether cardiovascular responses to mental stress tests are still predicting future BP over a 40-month period. Therefore, the aim of the present study was to examine whether measures of responses to laboratory-based challenges significantly improve predictions of BP among initially normotensive participants in long-term follow-up.

MATERIALS AND METHODS

Participants

A convenient sampling technique was used; participants were recruited from students and staff at Thammasat University and people living in the local community. The participants ranged in age from 18 to 65 years with males and females. All participants gave informed consent before participation of the study. Before data collection, the study protocol approval was obtained from the Ethics Committee of Thammasat University. All procedures were carried out with the written informed consent of the volunteers. Recruitment of participants and psychological tests were measured which have been described in elsewhere.[6] Shortly, after the beginning of the tests, the participants were asked to perform three mental stress tests (i.e., mental arithmetic, speech, and cold pressor tasks). A 5 min, serial subtraction task was used; participants were requested to subtract the number "13" repetitively starting from "1079" as quickly. During this task, a metronome was set at a frequency of 2 Hz to elicit time and pressure. Participants were given instructions to read and prepare a speech on an assigned topic for 2 min and speak for 3 min. A video camera was set up to record during the task; participants looked at the camera and talked continuously during the speech. For the cold pressor task, the participants were asked to put their right hand in the cold water for 2 min. The portapres continuous BP monitor was used to perform and measure hemodynamic parameters. After the 8 min resting period, the volunteers then underwent a set of mental stressors (i.e., mental arithmetic, speech, and cold pressor tasks), followed by an 8 min recovery period, in which they rested after each task. These are summarized below in Figure 1.

At the 40-month follow-up, individuals who had completed the initial assessment were contacted by telephone and invited to attend for reevaluation of BP. Those who agreed to participate were asked to refrain from caffeine, alcohol, and smoking for at least 2 h before the follow-up session. To start the session, participants were asked to sit quietly in a comfortable chair while initial resting BP and HR readings were obtained. BP was administrated by an Omron• M6 Comfort BP monitor (HEM-7211). The automated BP monitor was set to read and record BP at 5, 10, 15, and 18 min of the 20 min resting period, and the mean BP was calculated.

Data analysis and statistical analysis

Data for resting BP, HR, total peripheral resistance (TPR), and cardiac output (CO) were collected minute-by-minute and calculated between the 5 and 18 min readings because cardiovascular measures may increase in anticipation of an upcoming task. The study, therefore, excluded the two last readings from the computation of average baseline levels. Hemodynamic responses scores (i.e., diastolic BP [DBP], SBP, HR, CO, and TPR) for each task were calculated as the mean task level minus the mean of the final three baseline readings before each task.

Independent samples *t*-tests or Mann–Whitney tests were performed to indicate whether participants in the

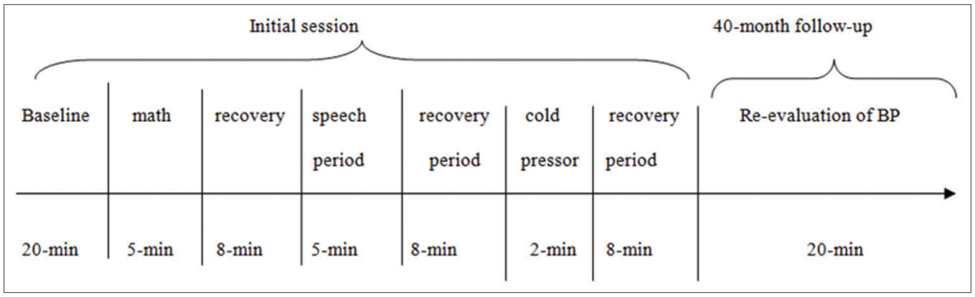

Figure 1: Summary of diagram shows stages of experimental protocol

follow-up differed from those who did not participate in the follow-up after a 40-month period. Pearson correlations were used to examine relationships between cardiovascular responses to psychological stress tests at the time of the initial session and BP levels after a 40-month of follow-up. Finally, a series of hierarchical regression analyses were performed to determine whether cardiovascular responses to mental stress predicted BP over a 40-month period independently of other variables (e.g., baseline cardiovascular activity and traditional risk factors; BMI, age, gender, and parental history of CVD).

RESULTS

Demographic and cardiovascular characteristics of stress responses

The average time of follow-up was 40.96 ± 1.13 (range 38.24–42.90) months. A total of 111 healthy volunteers (27 men and 84 women) participated in the study. Sixteen (14.41%) participants were not reexamined; two did not agree to participate due to relocation and 14 did not answer any E-mail or calls. The demographic and resting cardiovascular characteristics of the sample at baseline and follow-up are presented in Table 1. There were no significant differences in initial resting BP, HR, CO, TPR, BMI, gender, or family history of CVD between those who attended the follow-up and those who did not. However, those who attended follow-up showed higher SBP and DBP responses to the mental arithmetic task (21.64 ± 11.17 mmHg, 12.45 ± 8.05 mmHg, respectively) than those who did not attend follow-up (13.95 ± 11.82 mmHg, 7.72 ± 6.66 mmHg, respectively; t_s (109) >2.22).

Prediction of longitudinal changes in blood pressure after a 40-month follow-up

Bivariate correlations between cardiovascular reactions to psychological stress tests at initial testing and resting SBP and DBP and at a follow-up after a 40-month period were observed together with cardiovascular responses to mental arithmetic tasks. Only SBP at follow-up was related to SBP responses to the mental arithmetic tasks alone ($r = 0.241$, $P = 0.019$). A series of hierarchical regression analyses were performed to determine the contribution of cardiovascular responses to the prediction of follow-up resting BP. At step one, initial resting baseline BP activity was entered into the regression model. At step two, a set of traditional risk factors (i.e., initial age, initial BMI, sex, and family history of CVD) were entered into the regression model. Cardiovascular responses to a single psychological stress test (i.e., mental arithmetic, speech, and cold pressor tasks) were entered into the regression model at step three for cardiovascular responses that showed a significant association with future BP levels ($P < 0.05$); thus, SBP responses to mental arithmetic were the only measure of reactivity to be entered.

Table 1: Characteristics of Thai participants who completed baseline and follow-up sessions (*n*=95)

Characteristic	*N*	%	Mean	SD
Sex				
Male	21	22.11		
Female	74	77.89		
Family history of CVD status	40	42.11		
Age at initial (years)			32.16	10.18
BMI at initial session (kg/m^2)			22.06	4.34
SBP at initial session (mmHg)			110.47	9.69
DBP at initial session (mmHg)			59.97	6.78
SBP at follow-up session (mmHg)			114.33	10.46
DBP at follow-up session (mmHg)			65.59	8.26

In hierarchical logistic regression analyses, adjusted for baseline cardiovascular activity and traditional risk factors, SBP responses to the mental arithmetic task accounted for an additional 4.0% of the variance ($\beta = 0.192$, standard error = 0.083; $P = 0.023$); all predictors together accounting for 33.4% of the variance in follow-up SBP levels [Table 2].

In summary, these results suggest that exaggerated SBP responses to mental arithmetic predict follow-up SBP over a 40-month period above and beyond that of traditional risk factors albeit modestly. With respect to the prediction of future DBP, none of the measures of cardiovascular reactivity predicted future DBP; cardiovascular reactivity was unrelated to future DBP in the hierarchical regression analysis.

Table 2: Results of hierarchical linear regression analyses predicting a forty month SBP from baseline resting SBP, traditional risk factors, and SBP responses to mental arithmetic data in the Thai participants

Regression model	*B*	SE	β	*t*	Δ R^2
40-month SBP					
Step 1					
Baseline SBP	0.391	0.104	0.363	3.753***	0.132***
Step 2					
Age	0.110	0.095	0.107	1.158	
Sex[a]	6.227	2.380	0.248	2.616*	
FH[b]	1.111	1.970	0.053	0.564	
BMI	0.706	0.218	0.293	3.246**	0.162**
Step 3					
SBP responses to MA	0.192	0.083	0.205	2.313*	0.040*

MA - mental arithmetic; FH - family history of CVD; [a]sex: male=1, female=0 [b]family history of CVD: positive=1, negative=0 *P<.05, **P<.01, ***P<.001

DISCUSSION

The main findings of the present study were to find out whether hemodynamic responses to mental stress tests could predict a future increased BP after a 40-month follow-up. These findings are consistent with the results of previous studies, which support the reactivity hypothesis. The results of the present study support and extend these findings by suggesting that exaggerated cardiovascular reactions to psychological laboratory stress are associated with enhanced future BP and then may play a role in the development of hypertension.[6-10] However, only the cardiovascular reactions to serial subtraction were associated with increased BP. Further, after adjustment for baseline cardiovascular activity and traditional risk factors; SBP responses to mental arithmetic explained 4.0% of the variation of future SBP levels; the full regression model explained 33.4% of the variance of SBP after a 40-month follow-up, no analogous association was found in DBP or the prediction of future resting DBP. As such, the present study closely replicated the other previous studies. It is also noteworthy that none of the measures of cardiovascular responses to the speech or the cold pressor tasks were related to future SBP.

The results are congruent with previous studies indicating that cardiovascular responses to mental arithmetic tasks appear to have an impact on BP rather than other psychological stress tests (i.e., speech and cold pressor tasks). Further, a small number of previous studies have examined the duration of follow-up (short- and long-term) in the same sample. For example, Moseley and Linden used cardiovascular reactivity across three tasks (mental arithmetic, anger-recall, and handgrip tasks) to predict future BP levels after 3 years and at a 10 year follow-up among normotensive individuals.[10] They found that cardiovascular responsivity predicted future BP more strongly at a 3 year follow-up than at a 10 year follow-up. Similarly, follow-up data from a West of Scotland study revealed that SBP reactions to the paced auditory serial addition test predicted subsequent SBP levels more strongly at 5 years than at 12 years.[8,9] In the Whitehall II study, cardiovascular reactions to a Ravens matrices task predicted future SBP levels more strongly at 5 years than at a 10 year follow-up.[11,12] Thus, the findings of this review accord with empirical studies which is that SBP responses to mental arithmetic tasks predicted future SBP at 1 year follow-up more strongly than at a 40-month follow-up ($\Delta R^2 = 0.45$ and $\Delta R^2 = 0.40$, respectively). It is not clear why the relationships were stronger in the studies with shorter follow-ups. It may be the case that in studies with longer follow-up periods, attrition was an important factor; for example, fewer unhealthy individuals who may have taken part in the follow-up and therefore weakened any associations between reactivity and future BP. Further, Moseley and Linden suggested that stimulant hormone levels (e.g., stress hormones, growth hormones, and sex hormones) decline with an increasing older age, particularly after 40 years of age.[10] Those studies that examined reactivity and BP at two different follow-ups recruited middle-aged adult participants (an average age at entry was 37.23 ± 9.11). Hence, these changes coupled with changes in behavior (e.g., diet and exercise) are likely to contribute to changes in BP over time with longer follow-up periods, and so the contribution of cardiovascular reactivity may be reduced over time. Therefore, the present study found that shorter follow-up times were associated with better predictions of future SBP levels by SBP reactivity than longer follow-up times.

A few limitations of this study can be noted, which might have affected the results of the study. First, the number of the participants was a relatively small sample size. In addition, the effect sizes for SBP responses to mental arithmetic tasks were weaker than those reported at a 1 year follow-up in this study.[6] Further, the assessments of socioeconomic backgrounds and health statuses (e.g., hormones) are not examined. Despite the limitations noted above, the study extends previous research that has been completed in European and North American countries; BP reactivity significantly improved prediction models of future BP in a Thai sample. Through such investigation methods, vulnerable Thai participants may be more easily identified and directed toward appropriate screening. In addition, future research should examine the role of cardiovascular responses to acute psychological stressors in the prediction of future BP in non-Western samples. In the current study, 4.0% of the variability of future SBP was accounted for by SBP reactivity; a contribution similar to the 2%–12% found in previous Western studies whether with a short or long duration of follow-up.[6-14] Thus, BP reactivity appears to be a modest, independent predictor of future SBP.

Regarding the clinical implications, the results seem important to stress that hyperactivity of the sympathetic nervous system is associated with an increased BP. Therefore, psychological stressors may help to identify individuals at risk of CVD. Moreover, assessing cardiovascular responses to psychological stress may help guide therapeutic efforts to reduce high BP attenuation of hemodynamic reactions to psychological stressor using behavioral therapy, emotional control, mediation, stress management, or relaxation therapy might be one approach to reduce high BP levels. Many researchers have shown that emotional control, meditation, biofeedback control, or behavioral interventions are effective inventions to reduce BP and CVD risk.[15] Thus, attenuation of hemodynamic reactions to mental stress may potentially be used to assess the reduced risk of CVD.

CONCLUSIONS

Prospective analyses revealed that SBP responses to mental arithmetic tasks can predict future SBP levels after a 40-month follow-up in the Thai individuals, after controlling for baseline cardiovascular activity and traditional risk factors. Further, these relationships were maintained and still significant after 1 year and a 40-month follow-up period. The study offers evidence that heightened cardiovascular reactions to psychological stress, and especially mental arithmetic may be an independent role in the development of increased BP or hypertension, and extends previous findings for the Asian population.

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Conflicts of interest

There are no conflicts of interest.

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