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# Age-Dependent Autonomic Changes Following Immersion in Cool, Neutral, and Warm Water Temperatures

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Aquatic immersion has been reported to produce a significant number of physiological changes in blood pressure, heart rate variability (HRV), autonomic nervous system (ANS), and core temperature in young healthy subjects. The purpose of this study was to examine the impact of water immersion in younger and older populations, determining whether there are age related differences for ANS regulation measures in cool, neutral, and warm water. Vitals and ANS measures were collected from two samples representing different age-groups in the general population. It was found that water immersion produced a significant number of important physiologic responses such as decreased blood pressure and increased SVB during the warm water cycle. These changes are important components of ANS bioregulation and clearly seem to be influenced by water temperature during immersion. There was a statistically significant relationship between ANS activity manifested by heart rate variability and water temperatures.

Aquatic immersion has been reported to produce a significant number of physiological changes including changes in blood pressure, heart rate variability (HRV), autonomic nervous system (ANS), and core temperature in young healthy subjects (Becker, Hildenbrand, Whitcomb, & Sanders, 2009). In our previous study, we examined these physiologic changes across three different temperatures: cool (31.1 °C), neutral (36 °C), and warm (39 °C). A decrease in both mean blood pressure and diastolic pressures was seen in immersion states and was most pronounced in warm water. Heart rate also increased significantly in warm water when compared with cool and neutral water. Core temperature increased significantly in warm water compared with the other immersion temperatures.

These changes appeared to have been influenced by immersion temperature, impacting the relationship between ANS activity and HRV. Warm water immersion can produce increases in sympathetic power with small drops in sympathovagal balance from baseline. A rise in sympathovagal balance is associated with stress reduction, positive emotions, relaxation, and meditation (Thayer & Lane, 2000; Thayer & Siegle, 2002; Thayer, Newman, & McClain, 1994). Such physiologic

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changes can cause decreases in cardiac irritability, blood pressure, and anxiety (Thayer & Brosschot, 2005; Thayer & Lane, 2000; Thayer & Siegle, 2002; Thayer & Sternberg, 2006; Ziegelstein, 2007).

## Background

Physiologic effects linked with aquatic activity play an important role in human health. Both simple immersion and aquatic exercise exert a positive influence on some of the body's major systems, including the cardiovascular, musculoskeletal, autonomic nervous, and endocrine systems (Becker, 2004, 2009). These positive influences could possibly assist with some major public health issues such as cardiovascular disease, obesity, diabetes, asthma, and arthritis. Aquatic activity has also been used in the field of athletics and sports medicine due to its significant value for sport training and rehabilitation (Hamer & Morton, 1990). For these reasons, aquatic research has begun to focus on the many health benefits across a wide age span.

Research has determined that chest-depth immersion in water produces a large shift of blood from the extremities toward the thorax. Approximately 67% of this volume involves lung circulation with the remaining 33% of the volume in the heart (Arborelius, Balldin, Lila, & Lundgren, 1972; Arborelius, Balldin, Lilja, & Lundgren, 1972; Prins & Cutner, 1999; Svedenhag & Seger, 1992). The increase in blood volume within the pulmonary vasculature is housed in both the large pulmonary vessels as well as in smaller vessels. This creates an increase in lung stiffness, increasing the work of breathing and slightly decreasing vital capacity. The increase in cardiac blood volume distends the atria and creates an increase in end-diastolic volume. As a consequence, the heart responds with an increased force of contraction and an increase in both stroke volume and cardiac output. Cardiac efficiency is increased by these responses (Begin et al., 1976; Christie et al., 1990). This is an important aspect of chest-depth immersion, which has practical application for patients in cardiac rehabilitation or in recovery from cases of severe debilitation (Cider, Svealv, Tang, Schaufelberger, & Andersson, 2006).

Immersion also lowers peripheral resistance causing a reduction in the cardiac workload necessary for moving increased blood volumes during physical exertion, once again increasing the efficiency of the cardiovascular system (Arborelius et al., 1972). Therefore, using aquatic exercise as a means of cardiac rehabilitation can be beneficial, especially after ischemic heart injury caused by a decreased blood flow (Cider, Schaufelberger, Sunnerhagen, & Andersson, 2003; Cider, Sunnerhagen, Schaufelberger, & Andersson, 2005; Cider et al., 2006; Gabrielsen et al., 2000; Gruner Svealv et al., 2009; Jiang et al., 1994; Meyer & Leblanc, 2008; Mussivand et al., 2008; Tei et al., 1995; Tei & Tanaka, 1996a, 1996b). Over time, the cardiac muscle, as with all aging muscles, takes longer to achieve peak force and has an extended refractory period. This results in a lower maximum heart rate causing a reduction in consequent cardiac output (Bernhard & Laufer, 2008).

The ANS is the major control mechanism for regulating cardiovascular activity including blood pressure, peripheral vascular resistance, heart rate, contractility, and blood volume through renal forces. It also controls gastrointestinal motility and secretion, renal and bladder function, visual alterations, thermoregulation, and a number of mental processes (Guyton & Hall, 1996). There are two major subdivisions that make up the ANS, the sympathetic and parasympathetic systems, which are located in the brainstem. The sympathetic nervous system (SNS) controls the fight or flight responses of the body while the parasympathetic nervous system (PNS) controls relaxation and repose. The ANS is a complex system of interconnections and neural regulatory mechanisms creating rapid response rates capable of doubling the heart rate in a matter of a few seconds (Guyton & Hall, 1996).

The ANS plays a key role in the mechanisms of most cardiovascular diseases, including hypertension and myocardial infarction and is thought to be the biophysiologic control panel in many other diseases such as diabetes, kidney issues, and other inflammation diseases (Thayer & Sternberg, 2006). The aging process involves changes in the autonomic control of the heart, with increased sympathetic tone and reduced parasympathetic tone, resulting in an increase in resting heart rate and blunted cardiovagal baroreflex sensitivity (Cademartiri, La Grutta, de Feyter, & Krestin, 2008; De Meersman & Stein, 2007; Kaye & Esler, 2008). Physical activity levels play a role in the magnitude of this reduction, with a protective value of exercise in sustaining parasympathetic cardiovascular control (Shi et al., 2008).

Aquatic immersion in thermoneutral temperatures affects the ANS by lowering sympathetic power and increasing vagal influence simultaneously. The response of the ANS to immersion is similar to that seen with other relaxation techniques such as meditation (Miwa, Sugiyama, Mano, Iwase, & Matsukawa, 1997; Nishimura & Onodera, 2000, 2001; Perini & Veicsteinas, 2003). Immersion in warm water is generally considered pleasurable and creates an almost universal feeling of relaxation. It is known that positive emotional states are associated with sympathovagal balance (McCraty, Atkinson, & Rein, 1996; McCraty, Choplin-Barrios, Rozman, Atkinson, & Watkins, 1998; Thayer & Sternberg, 2006). Because the ANS is one of the most rapidly responsive bioregulatory control functions in the body, changes within this system should be clearly measurable during warm water immersion. These changes should also mirror other functional states such as relaxation or emotional comfort.

Monitoring serum catecholamine levels, galvanic skin responses (polygraphs), salivary cortisols, and heart rate variability (HRV) have been used to examine ANS function. The measurement of blood hormones is very useful but because changes within the ANS are instantaneous, a single blood draw does not allow continuous measurement of sympathetic and parasympathetic activities. HRV has gained popularity as a prime method of measuring ANS activity because it is noninvasive, inexpensive, and gives real-time information about both of the systems that make up the ANS (Stauss, 2003; Task Force of the European Society of Cardiology, 1996; Thayer & Brosschot, 2005). Fear and stress have been shown to increase SNS activity, while relaxation, meditation, and thermoneutral water immersion increase PNS activation (Mano, Iwase, Yamazaki, & Saito, 1985). An increase in SNS activation is shown to correlate with adverse cardiac events like arrhythmias, while increased PNS activation is linked with a decrease in such cardiac events (Thayer & Brosschot, 2005). As a result, HRV has become a vital tool in the assessment of ANS activity and is commonly used in coronary care units.

HRV analysis stands upon the knowledge that a normal heart beats regularly but does so with instantaneous variation. This variation depends on frequency of respiration, ANS activity, balance between the PNS and SNS systems, and other factors such as the gastrointestinal system. Using mathematical analysis, HRV may be broken into frequency spectra powers; by measuring the power of these various spectra, the influence of the ANS subcomponents can be assessed. This additional analysis of the SNS and PNS is referred to as sympathovagal balance (SVB; Task Force, 1996).

Previous work in our laboratory demonstrated a significant effect of immersion temperature upon a number of ANS-driven variables in a young healthy population (Becker et al., 2009). Aging has been associated with altered ANS responses, but since we have not found research assessing the impact of aging in immersion-produced responses, this study was conceptualized. Older individuals may be the population most involved with aquatic exercise, and immersion temperature may be an important variable in the safety of such exercise activities from a cardiovascular standpoint, understanding the impact of temperature upon the ANS in an older population is relevant.

## Purpose

The purpose of this study was to examine the impact of water immersion in younger (18–30 years) and older (45–65 years) populations, determining whether there are age related differences for ANS regulation measures in cool, neutral, and warm water. It was the intent of this study to focus on age differences on physiological measures, including blood pressure, heart rate, thermoregulation, and peripheral circulation.

# Method

Vitals and ANS measures were collected from two samples representing different age groups in the general population. The college-age sample consisted of 16 students between the ages 19 and 30 (mean 21.8 years, *SD* 2.72), nine of whom were female. The second sample contained 14 people between the ages of 42 and 65 (mean 52.29 years, *SD* 6.66), eight of whom were female.

This study was approved through the university's Institutional Review Board and all participants first signed informed consent forms. Afterward, percent body fat, resting heart rate, and blood pressure were taken. Participants ingested a radiofrequency core temperature transmitter—CoreTemp—that tracked their temperature throughout the study. A BioPac (BioPac Systems Inc, Goleta CA) biologic monitoring system was used for peripheral blood flow, which was taped to the great toe medial surface of each participant to continuously measure peripheral circulation. Additional electrodes were attached to measure heart rate, and electrocardiogram (ECG) was placed on the right supraclavicular, right iliac, and left apex.

Participants rested poolside for six minutes (minute 0 through minute 5) after initial measurements and then immersed in a cool (31.1 °C) tub for 24 min (minutes 6 through 29). Vitals (i.e., heart rate, core temperature, and blood pressure) were recorded four times while in the cool tub: at the tail-ends of the 11th, 17th, 23rd, and 29th minutes. ANS data (i.e., VLF, HF, and SVB) were recorded three times while in the cool tub: at the tail-ends of the 17th, 23rd, and 29th minutes. Upon exiting the cool water, subjects rested poolside for 12 min (minute 30 through minute 41). Vitals and ANS data were recollected half way through this first recovery period.

Participants then immersed in neutral (36 °C) water for 24 min (minutes 42 through 65) where vitals and ANS data were collected again, followed by another poolside recovery for 12 min (minutes 66 through 77). As before, vitals were retaken at the half point of the recovery period. Finally, participants immersed in a warm (39 °C) tub for 24 min (minutes 78 through 101) before sitting at poolside for a final 12 min (minutes 102 through 114). Vitals were recorded at both the half point and end of the third recovery period; ANS data were collected only at the half point of the final recovery period. All immersion was in a sitting-up position with water level just below the clavicle.

A fast-Fourier transform of the ECG into ANS data were completed once BioPac data were sufficiently cleaned. ANS data contained power spectrum data in very low frequency (VLF = 0.04HZ) and high frequency (HF = 0.15–0.4HZ) and sympathetic vagal balance. Similar to the approach taken for the vital measures, ANS data were assessed for baseline and recovery periods, but were recorded at three points rather than four during the immersion periods. Table 1 provides descriptive statistics. Values listed in the table for the immersion periods represent the average of measures taken while in water, and values listed for the third recovery period represent the average of the final two measures taken.

**Table 1 Descriptive Statistics**

| | Sample | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | College-Age | | | | Age 42–65 | | | |
| Variable | *Min* | *Max* | *Mean* | *sd* | *Min* | *Max* | *Mean* | *sd* |
| **Baseline** | | | | | | | | |
| Heart rate | 48 | 83 | 67.412 | 10.000 | 52 | 84 | 70.5 | 10.029 |
| Core temp | 36.44 | 37.34 | 37.05 | 0.296 | 34.81 | 37.97 | 36.789 | 0.807 |
| Systolic BP | 98 | 130 | 112.118 | 8.690 | 98 | 169 | 125.929 | 17.256 |
| Diastolic BP | 56 | 86 | 72.235 | 8.164 | 56 | 109 | 83.429 | 12.629 |
| VLF | 6.608 | 16.620 | 9.910 | 3.060 | 5.735 | 14.499 | 8.540 | 2.519 |
| HF | 0.631 | 2.598 | 1.079 | 0.584 | 0.456 | 1.438 | 0.813 | 0.366 |
| SVB | 2.011 | 4.280 | 3.602 | 0.611 | 2.039 | 4.698 | 3.889 | 0.693 |
| **Cool** | | | | | | | | |
| Heart rate | 48 | 76.5 | 62.694 | 9.068 | 45.75 | 90 | 64.321 | 11.618 |
| Core temp | 36.80 | 37.648 | 37.212 | 0.281 | 35.998 | 38.877 | 37.316 | 0.718 |
| Systolic BP | 91 | 118 | 102.529 | 7.293 | 99.750 | 148.250 | 124.821 | 13.179 |
| Diastolic BP | 51.5 | 70.5 | 61.382 | 5.053 | 61.000 | 102.000 | 78.446 | 10.907 |
| VLF | 6.608 | 16.620 | 9.910 | 3.060 | 3.886 | 20.259 | 10.662 | 4.073 |
| HF | 0.636 | 4.992 | 1.991 | 1.253 | 0.632 | 6.228 | 1.711 | 1.545 |
| SVB | 1.131 | 3.875 | 2.636 | 0.819 | 1.730 | 4.055 | 3.148 | 0.820 |

*(continued)*

**Table 1 *(continued)***

| | Sample | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | College-Age | | | | Age 42–65 | | | |
| Variable | *Min* | *Max* | *Mean* | *sd* | *Min* | *Max* | *Mean* | *sd* |
| **1st Recovery** | | | | | | | | |
| Heart rate | 45 | 76 | 60 | 9.738 | 47.000 | 84.000 | 62.929 | 10.065 |
| Core temp | 36.79 | 37.63 | 37.269 | 0.292 | 36.720 | 37.910 | 37.165 | 0.343 |
| Systolic BP | 94 | 134 | 113.118 | 10.487 | 109.000 | 153.000 | 130.357 | 15.214 |
| Diastolic BP | 61 | 84 | 75.235 | 6.440 | 67.000 | 103.000 | 90.071 | 10.916 |
| VLF | 4.212 | 22.228 | 12.233 | 4.576 | 6.896 | 19.637 | 10.873 | 3.468 |
| HF | 0.684 | 2.421 | 1.344 | 0.568 | 0.613 | 2.450 | 1.057 | 0.523 |
| SVB | 2.684 | 5.765 | 3.791 | 0.781 | 2.379 | 4.932 | 3.778 | 0.661 |
| **Neutral** | | | | | | | | |
| Heart rate | 46.3 | 75.3 | 60.406 | 7.933 | 42.500 | 85.250 | 63.446 | 11.817 |
| Core temp | 36.58 | 37.448 | 37.111 | 0.261 | 36.703 | 37.765 | 37.085 | 0.308 |
| Systolic BP | 87.8 | 112.80 | 98.176 | 6.883 | 99.000 | 134.250 | 115.321 | 11.300 |
| Diastolic BP | 48 | 67.5 | 56.632 | 5.545 | 57.750 | 81.500 | 71.875 | 7.688 |
| VLF | 19.695 | 48.321 | 30.560 | 8.190 | 7.911 | 23.017 | 12.094 | 4.333 |
| HF | 0.596 | 3.542 | 1.563 | 0.888 | 0.652 | 3.046 | 1.574 | 0.893 |
| SVB | 1.608 | 3.903 | 2.864 | 0.700 | 1.239 | 4.206 | 3.018 | 0.991 |
| **2nd Recovery** | | | | | | | | |
| Heart rate | 50 | 69 | 59.882 | 5.529 | 45.000 | 81.000 | 59.929 | 11.083 |
| Core temp | 36.79 | 37.41 | 37.167 | 0.211 | 36.680 | 37.860 | 37.071 | 0.323 |
| Systolic BP | 100 | 132 | 113.647 | 8.485 | 103.000 | 156.000 | 133.143 | 14.507 |
| Diastolic BP | 67 | 94 | 79 | 6.748 | 72.000 | 108.000 | 92.500 | 11.387 |
| VLF | 8.282 | 20.159 | 13.335 | 3.955 | 6.792 | 19.182 | 11.358 | 3.392 |
| HF | 0.794 | 3.077 | 1.533 | 0.678 | 0.527 | 2.650 | 1.109 | 0.602 |
| SVB | 1.947 | 4.277 | 3.553 | 0.644 | 1.628 | 4.785 | 3.834 | 0.767 |
| **Warm** | | | | | | | | |
| Heart rate | 68 | 101 | 81.588 | 8.711 | 57.750 | 101.750 | 80.405 | 12.219 |
| Core temp | 37.335 | 38.05 | 37.643 | 0.205 | 37.015 | 38.288 | 37.496 | 0.352 |
| Systolic BP | 83.5 | 120 | 102.610 | 9.014 | 96.750 | 131.500 | 114.786 | 10.423 |
| Diastolic BP | 40.75 | 65.5 | 53.176 | 6.109 | 58.250 | 76.333 | 66.738 | 5.717 |
| VLF | 9.637 | 19.580 | 15.394 | 2.982 | 2.735 | 15.772 | 6.916 | 3.442 |
| HF | 0.271 | 1.323 | 0.587 | 0.291 | 0.305 | 3.123 | 1.101 | 0.851 |
| SVB | 1.857 | 4.782 | 3.893 | 0.710 | 2.384 | 4.282 | 3.406 | 0.744 |

| | Sample | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | College-Age | | | | Age 42–65 | | | |
| Variable | *Min* | *Max* | *Mean* | *sd* | *Min* | *Max* | *Mean* | *sd* |
| **3rd Recovery** | | | | | | | | |
| Heart rate | 51 | 92 | 67.941 | 9.384 | 57.500 | 86.500 | 72.071 | 9.673 |
| Core temp | 37.475 | 38.075 | 37.728 | 0.189 | 37.185 | 38.650 | 37.790 | 0.382 |
| Systolic BP | 92.5 | 131 | 108.559 | 10.484 | 93.500 | 137.500 | 119.321 | 13.028 |
| Diastolic BP | 56 | 80 | 66.941 | 6.169 | 59.500 | 95.000 | 78.214 | 10.297 |
| VLF | 7.032 | 18.033 | 10.548 | 2.894 | 5.480 | 14.464 | 8.242 | 3.021 |
| HF | 0.619 | 2.114 | 1.038 | 0.387 | 0.436 | 1.330 | 0.696 | 0.310 |
| SVB | 2.364 | 4.956 | 3.920 | 0.685 | 2.775 | 4.694 | 4.133 | 0.570 |

*Note.* $N = 31$ (17 College-Age; 14 Age 42–65)

## Statistical Methodology

As the goal of this study was to compare the potentially unique physiological effects of water immersion on younger and older people, independent samples *t* tests were conducted. Independent samples *t* tests were an appropriate statistical method, because data were derived from independent groups who experienced the same conditions at the same time points. Moreover, *t* tests allow for the inference of significance when sample size (and consequently statistical power) is low—a valuable feature considering the limited sample size of the study. Tests indicated whether there was evidence that college-age people physiologically respond to water immersion in a manner that was significantly different from people age 42–65. Specifically, change scores—or the amount of increase/decrease in physiological measures between a period and its preceding period—were compared. For a limited number of these outcome measures, Bartlett's tests for equal variances suggested that the assumption of equal variances in each sample was invalid (likely a consequence of small sample size). In such cases, Mann-Whitney tests were also conducted to ensure that statistically significant differences reported by *t* tests were reliable (Rosner, 1995).

The study not only tested for age-differentiated responses to water immersion, but also water temperature. This approach required multiple tests to be performed on the dataset, increasing the likelihood of Type I errors. To combat against wrongly rejecting null hypotheses, a Bonferroni correction was employed by dividing the traditional 0.05 alpha level by 6—the number of change-scores examined for each of the vital and ANS measures. This lowered the cutoff point for statistical significance to 0.008. Although the examination of multiple outcome measures (i.e., vital and ANS measures) meant that an even stricter Bonferroni correction could have been used, the limited size of the dataset means that statistical power is already low. A stricter correction would have unduly increased the likelihood of a Type II error (Abdi, 2007). Regardless, it may be best to regard the results presented here as preliminary and/or exploratory due to the need to collect larger samples and the dearth of literature focused on the relationships between age, water temperature, and physiological response to immersion. Significance test results at the unadjusted and Bonferroni-adjusted levels are reported in the results section and tables.

# Results

Table 2 presents results of independent-samples $t$ test analyses that compare vital measures across immersion states. Table 3 presents results of independent-samples $t$ test analyses that compare heart rate variability across immersion states. In many instances, the samples respond similarly to immersion, particularly with respect to vital measures. In some cases, however, samples responded very differently—particularly on ANS measures. Differences in vital and HRV scores were also graphed as a means to visually represent the relationships between age, water temperature, and physiological response to immersion. The main findings are now outlined.

## Vital Measures

***Heart Rate.*** The heart rates of the two samples responded similarly across most immersion states, with perhaps one exception occurring in the final recovery period. Heart rates for both samples were lower in the cool tub, first recovery, neutral tub, and second recovery periods than at baseline. Warm water induced a dramatic increase in heart rate for both samples. Upon exiting warm water, both samples experienced a significant drop in heart rate, but the heart rates of those in the college-age sample dropped more—even four beats per minute below their resting baseline heart rates and somewhat closer to rates recorded in the cool tub, first recovery, neutral tub, and second recovery periods. The finding that the heart rates in the college-age sample dropped significantly more upon exiting the warm tub was significant at the 0.05 level, but not at the more stringent 0.008 Bonferroni-adjusted level. Thus, it is possible that the difference found between the samples was merely a Type I error. A graph of heart rate changes by immersion status for both samples is presented in Figure 1.

***Core Temp.*** Similar to what was found for heart rate, the core temperatures of the two samples responded similarly across most immersion states, with the final recovery period being the possible lone exception. As shown in Figure 2, the core temp of both samples exhibited a curvilinear pattern in the cool tub, and although the core temp of the age 42–65 sample peaked later and 0.5 °C higher, no statistically significant differences between samples were found in comparisons where the four core temp measures were averaged together and then compared (as shown in Table 1). Moreover, the samples responded very similarly in the other tubs. In the final recovery period, however, the core temp of the college-age sample dropped significantly more than the age 42–65 sample. This difference was significant only at the 0.05 level, however, and not the more stringent 0.008 level. Thus there is again the possibility that finding that age 42–65 sample lowered core temp more slowly from the elevated levels that both samples achieved while immersed in the warm tub is a Type I error.

***Blood Pressure.*** As presented in Figure 3, changes in systolic and diastolic blood pressure during the immersion cycles were generally similar for both samples, although the older group pressures remained higher than the younger group throughout. Immersion in the cool tub is the lone stage in which the samples potentially differed—and only on systolic pressure. Although systolic pressure

**Table 2 Vital Scores by Water Immersion Status, College-Age, and Age 42–65⁺**

| Vital Measure | Sample | Baseline | Cool | 1st Recovery | Neutral | 2nd Recovery | Warm | 3rd Recovery |
|---|---|---|---|---|---|---|---|---|
| Heart rate | College Age | 67.412 | 62.676 | 60.000 | 60.382 | 59.882 | 82.309 | 67.765* |
| — | Age 42–65 | 70.500 | 64.321 | 62.929 | 63.446 | 59.929 | 80.405 | 72.071* |
| Core temp | College Age | 37.051 | 37.212 | 37.269 | 37.111 | 37.167 | 37.643 | 37.728* |
| — | Age 42–65 | 36.789 | 37.423 | 37.165 | 37.085 | 37.071 | 37.496 | 37.790* |
| Systolic | College Age | 112.118 | 102.485* | 113.118 | 98.147 | 113.647 | 102.603 | 108.559 |
| — | Age 42–65 | 125.929 | 124.821* | 130.357 | 115.321 | 133.143 | 114.786 | 119.3214 |
| Diastolic | College Age | 72.235 | 61.382 | 75.235 | 56.632 | 79.000 | 53.1765 | 66.765 |
| — | Age 42–65 | 83.429 | 78.446 | 90.071 | 71.875 | 92.500 | 66.738 | 78.214 |

⁺Significance indicates that the samples' change scores are significantly different from one another per Independent Samples T Test analyses.

*$p < .05$; **$p < .008$ Bonferroni adjusted level; 2-tailed

*Note.* $N = 31$ (17 college age; 14 age 42–65)

decreased for both samples in cool water, the systolic pressure of the college-age sample decreased significantly more than it did for the other sample. This difference between samples, however, was only statistically significant at the 0.05 level, and not the more stringent 0.008 Bonferroni-adjusted level.

## ANS Measures

***VLF.*** The VLF of both samples initially responded similarly, but differences emerged at the neutral water stage. Neutral water induced an increase in the VLF power spectral data (PSD) of the age 42–65 sample, but lowered the VLF PSD of the college-age sample. The samples also differed in how they responded in the second recovery period, with the VLF PSD of the college-age sample exhibiting an increase. There were differences in how the samples responded in the third recovery period as well. Both samples saw an increase in VLF PSD toward baseline rates, but the VLF PSD of the younger sample increased more. All of these differences in VLF response, however, are only significant at the 0.05 level rather than the 0.008 level. A graph of VLF changes by immersion status for both samples is presented in Figure 4.

**Table 3 ANS Scores by Water Immersion Status, College-Age and Age 42–65+**

| ANS Measure | Sample | Baseline | Cool | 1st Recovery | Neutral | 2nd Recovery | Warm | 3rd Recovery |
|---|---|---|---|---|---|---|---|---|
| VLF | College Age | 10.291 | 12.890 | 12.787 | 12.346* | 13.329* | 6.568* | 10.317 |
| — | Age 42–65 | 8.540 | 10.662 | 10.873 | 12.094* | 11.358* | 6.916* | 8.242 |
| HF | College Age | 1.026 | 1.455 | 1.283 | 1.334* | 1.581* | 0.609** | 1.029** |
| — | Age 42–65 | 0.813 | 1.711 | 1.057 | 1.574* | 1.109* | 1.101** | 0.696** |
| SVB | College Age | 3.580 | 3.413 | 3.777 | 3.494** | 3.423 | 4.002** | 3.904** |
| — | Age 42–65 | 3.889 | 3.148 | 3.778 | 3.018** | 3.834 | 3.406** | 4.133** |

+Significance indicates that the samples' change scores are significantly different from one another per Independent Samples T Test analyses.

*$p < .05$; **$p < .008$ Bonferroni adjusted level; 2-tailed

*Note.* $N = 29$ (16 college age; 13 age 42–65)

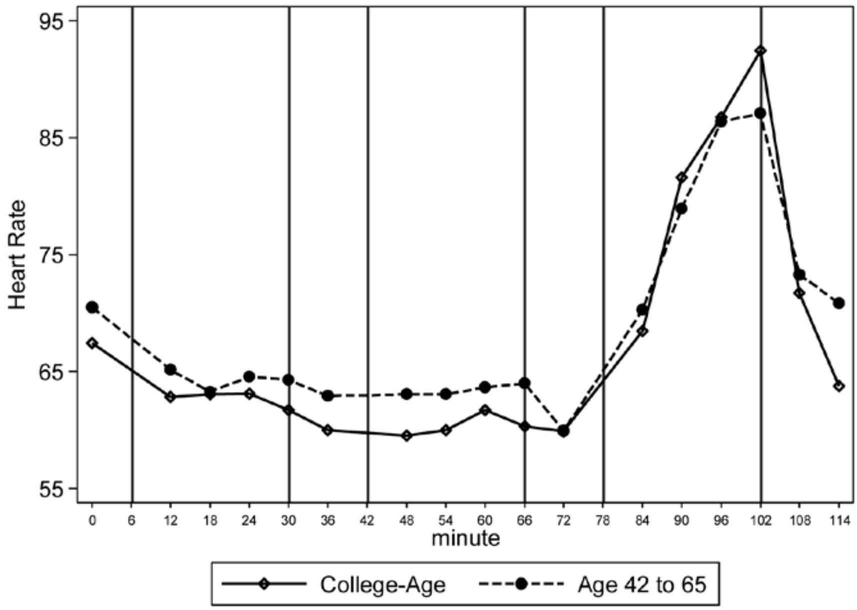


**Figure 1** — Heart rate by immersion status, college age, and age 42 to 65.

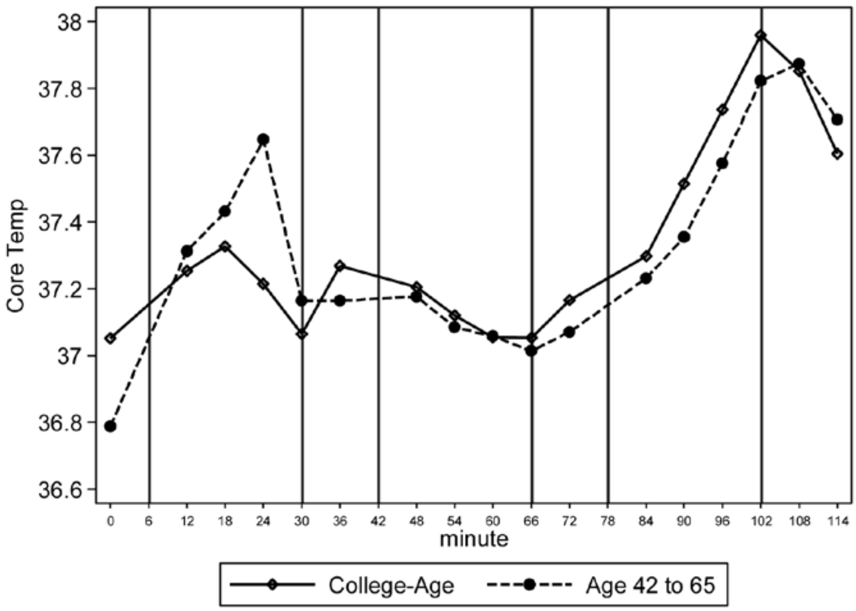


**Figure 2** — Core temp by immersion status, college age, and age 42 to 65.

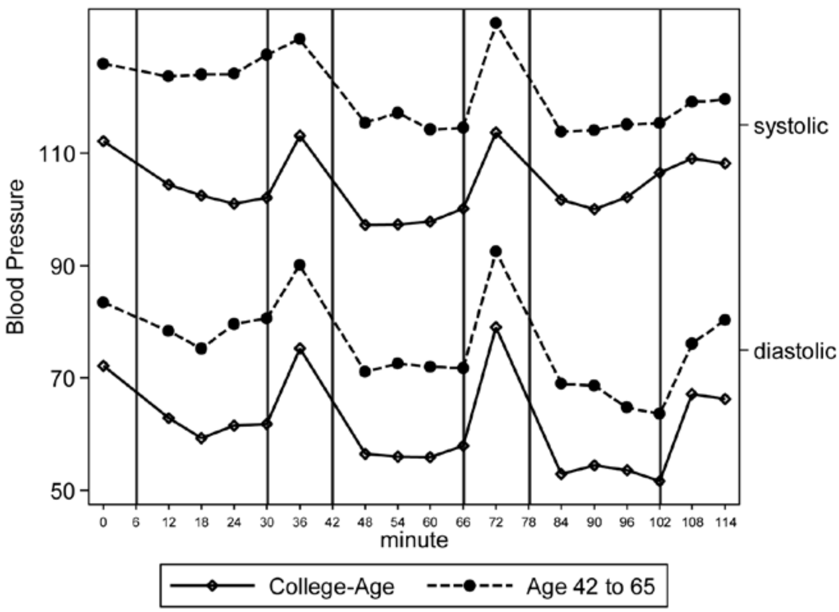


**Figure 3** — Blood pressure by immersion status, college age, and age 42 to 65.

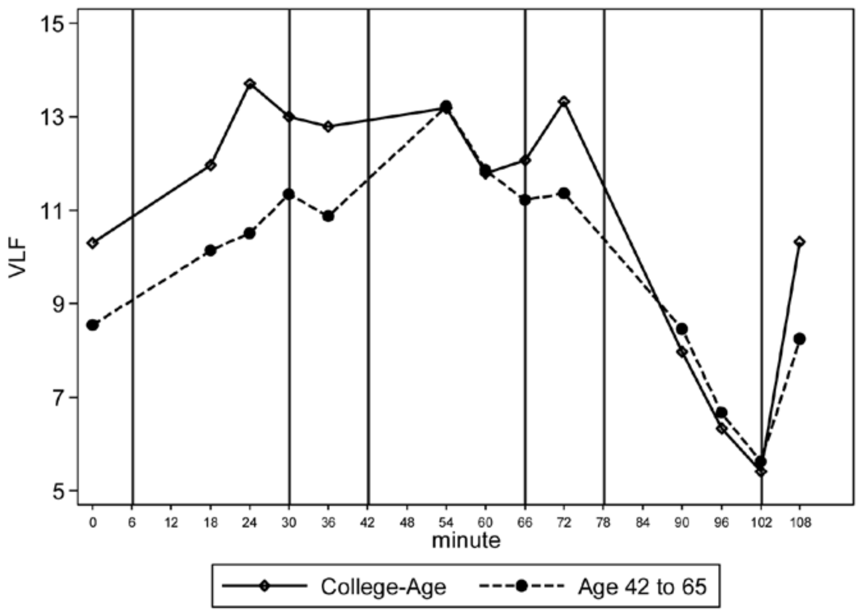


**Figure 4** — VLF by immersion status, college age, and age 42 to 65.

***HF.*** As was the case with VLF PSD change-scores, differences between the two samples emerged at the neutral water stage. The HF PSD of the age 42–65 sample exhibited a curvilinear pattern over time in the neutral tub, whereas the HF PSD of the college-age sample was relatively flat. This difference in response, however, was only significant at the 0.05 level. In the second recovery period that followed neutral tub immersion, HF for the college-age sample increased but it decreased for the age 42–65 sample. This difference was significant at the 0.008 level. The samples also responded differently in warm water, with the college-age sample experiencing an overall larger decrease in HF PSD than the age 42–65 sample (this difference was also significant at the 0.008 level). Finally, the samples responded differently in the third recovery period as well (Figure 5). The HF PSD of the college-age sample increased, and that of the age 42–65 sample decreased (significant at the 0.008 level).

A few of HF outcome measures violated the *t* test assumption of homogeneity of variance across samples. Thus, Mann-Whitney tests—in which the assumption of equal variance is relaxed—were also conducted and the tests found the same statistically significant differences reported by *t* tests, with the exception that differences in how the samples responded at the 2nd recovery period became statistically significant at the 0.05 level rather than the 0.008 level.

***SVB.*** Differences between the two samples did not emerge until the second recovery period. Upon leaving the neutral tub, the SVB of the college-age sample saw a slight decrease, whereas that of the age 42–65 sample increased. The samples

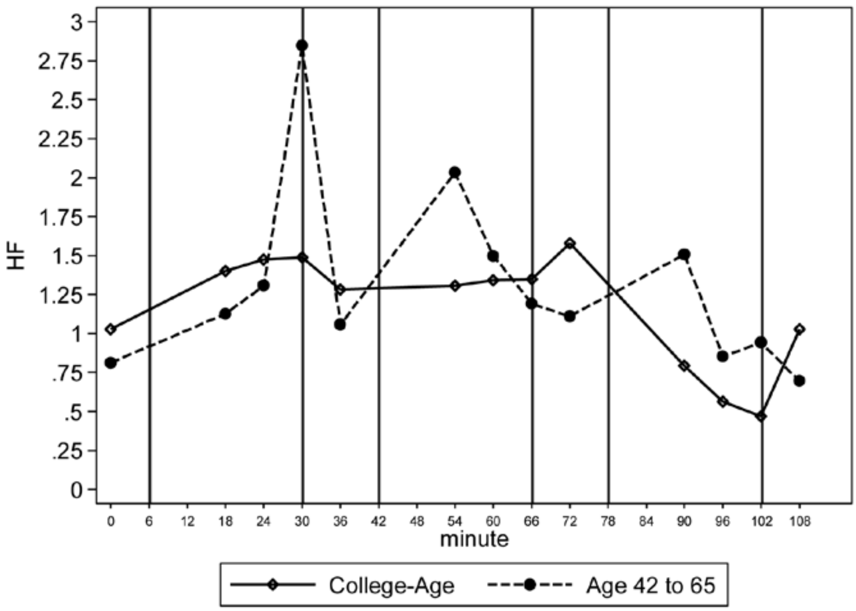


**Figure 5** — HF by immersion status, college age, and age 42 to 65.

also responded dissimilarly in the warm tub. On the whole, the college-age sample experienced a decrease in SVB while immersed in warm water, but the SVB of the age 42–65 sample increased. A final difference was found in the third recovery period. The SVB the age 42–65 sample increased, but that of the college-age sample decreased (Figure 6). All of these reported differences were statistically significant at the more stringent 0.008 Bonferroni-adjusted level (Table 3).

## Discussion

In our study of both healthy young college-aged and older healthy adults, water immersion produced a significant number of important physiologic responses such as decreased blood pressure and increased SVB during the warm water cycle. These changes are important components of ANS bioregulation and clearly seem to be influenced by water temperature during immersion. There was a statistically significant relationship between ANS activity manifested by heart rate variability and water temperatures.

Cool water produced a dramatic rise from baseline in sympathetic power (VLF PSD), with a drop in ANS balance (SVB), which likely demonstrates an increased physiologic stress response, even though the water temperature was not dramatically low. Most subjects did not feel cold upon initial submersion, although as time passed with no muscle activity, most felt quite chilled. Surprisingly, neutral immersion still produced a rise in sympathetic power though far smaller, and a smaller drop in SVB from baseline.

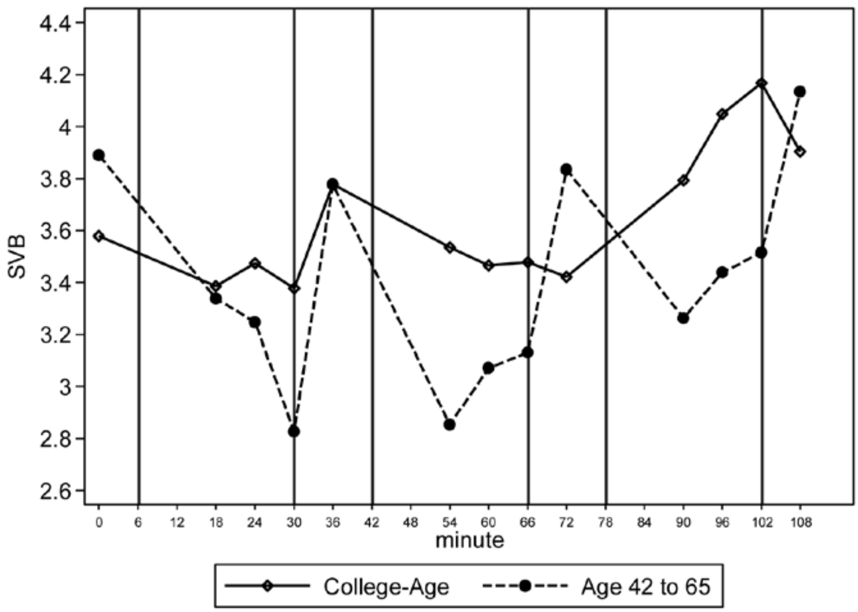


**Figure 6** — SVB by immersion status, college age, and age 42 to 65

Warm water immersion produced a slight rise in sympathetic power (VLF PSD) from baseline, but a statistically significant increase in SVB that was also above baseline measurement when compared with cool and neutral immersion temperatures. Elevated SVB lasted throughout the last recovery period of the study. An elevation in SVB in other studies has been associated with a reduction in stress, positive emotions, relaxation, and meditation (Thayer et al., 1994). Physiologic change of this magnitude has also been associated with a decrease in cardiac irritability, a decrease in blood pressure, and a lower anxiety level (Thayer & Brosschot, 2005; Ziegelstein, 2007).

Decreases in both mean blood pressure and diastolic pressures were observed during all periods of immersion, with both the warm water immersion period and the third recovery period demonstrating the most pronounced effects. These findings were parallel to findings in prior studies that found immersion lowers peripheral resistance, causing a reduction in the cardiac workload necessary for moving increased blood volume (Arborelius, Balldin, Lila et al., 1972; Arborelius, Balldin, Lilja et al., 1972; Becker et al., 2009). This may be an important clinical effect with both potential significant consequences in both short term and longer term. The short term effect may be to produce symptomatic hypotension upon exit from warm water immersion; however, the longer term effect may be to produce a drop in diastolic blood pressure in individuals with hypertension. This effect may persist for hours or even a day in some individuals and thus the aquatic environment may possibly be a useful therapeutic venue. None of our subjects were hypertensive at intake and we were unable to demonstrate this potentially beneficial effect during this study; however, none of our subjects demonstrated a clinically symptomatic drop in either mean or diastolic pressure sufficient to cause concern. It is probable that the decrease in peripheral vascular resistance may produce an improvement in muscle perfusion and possibly open insulin receptor sites. This may be the physiologic cause of a report of lowered insulin requirements in patients with diabetes following warm water immersion (Hooper, 1999).

We anticipated that there would be substantial differences between subject groups. Previous research has shown that HRV declines with aging, and other studies have demonstrated a slowing of physiologic responses across the age span (Boutcher, Cotton, Nurhayati, Craig, & McLaren, 1997; De Meersman & Stein, 2007; Fukusaki, Kawakubo, & Yamamoto, 2000; Leicht, Allen, & Hoey, 2003; Stein, Ehsani, Domitrovich, Kleiger, & Rottman, 1999; Ueno, Hamada, & Moritani, 2002; Wood, Hondzinski, & Lee, 2003). We saw little of this reduced responsiveness in our older subject group. The mean age of our older subject group was 52.3 (range 42–65), not elderly, as in some prior work, but still old enough to anticipate some physiologic appearance of HRV decrease. Studies have shown a relationship between fitness levels and HRV, with more fit populations demonstrating greater heart rate variability (Buchheit, Simon, Piquard, Ehrhart, & Brandenberger, 2004; Galetta et al., 2005; Tuomainen, Peuhkurinen, Kettunen, & Rauramaa, 2005). Our older group was quite physically active, thus perhaps obscuring the effects of aging upon autonomic bioregulation in this subject group.

Autonomic nervous system effects such as these have been found to be associated with a number of important physiologic consequences. The ability of the body to respond quickly to physical changes in the environment is essential to survival. Higher heart rate variability implies increased parasympathetic control over the nervous system, because vagal cardiac responses are on the order of seconds, whereas sympathetic influences are in the order of milliseconds. While the need for mounting a rapid sympathetic system response to physiologic stress is arguably the most important ability, many studies have shown that sustained sympathetic dominance over the ANS places immense burdens upon the body and ultimately results in a number of pathological conditions. This excessive sympathetic influence has been suggested to be associated with premature aging, cardiac disease, depression, and immune dysfunction (Karemaker, 1999; Lombardi, 2002; Thayer & Lane, 2000, 2007; Thayer & Sternberg, 2006).

Contrastingly, decreased sympathetic influence with increased balance between the sympathetic and parasympathetic components has been associated with increased prefrontal brain activity (Lane et al., 2009). The prefrontal cortex is a brain region that is active in controlling cardiac function, as well as several deep brain structures that are important in mood state regulation, working memory, and attention set. Hypoactivity of the prefrontal area results when the normally active parasympathetic nervous system loses its inhibitory effect upon the sympathetic nervous system. This situation has been noted in many disease states, including anxiety disorders, poorer working memory, and increased cardiac irritability and heart rate dysregulation (Thayer & Lane, 2009). Performance in a variety of cognitive tasks is positively associated with higher HRV and conversely is reduced in individuals with lower HRV (Hansen, Johnsen, & Thayer, 2003; Hansen, Johnsen, Sollers, Stenvik, & Thayer, 2004). Thus there seems to be a link between important physiologic processes and psychological and cognitive processes.

The most important finding in our study was the association of warm water immersion with increased sympathovagal balance. Other methods of increasing SVB have been developed and studied, including biofeedback, meditation, and some medications (Nolan, Jong, Barry-Bianchi, Tanaka, & Floras, 2008). Training in these techniques has produced positive effects upon a number of cognitive processes, including affect and mood state, working memory, and executive function (Thayer & Siegle, 2002; Thayer et al., 1994). While the training is not particularly complex, it does require time and persistence. In contrast, warm water immersion is readily available to nearly all individuals, does not take a significant amount of time, and is pleasurable and safe.

### Study Limitations

This study assessed 16 college-aged individuals, and 14 older individuals, a fairly small number of subjects. There was considerable variance between subjects in response magnitude, although remarkably little variance in direction of response. It is thus possible that a larger sample size would give different results. All subjects were healthy and free from regular medications, with the exception of two of the older individuals who were on statins, a category believed to be free of ANS effects

The water temperatures chosen were within a narrow range. Perhaps 31.1 °C was not cool enough or 39 °C warm enough. In preliminary work for this study, a lower temperature was used, but subjects chilled and started to shiver while in the 24-min immersion period. This affected the ECG pickup to the degree of concealing the signal with muscle artifact making the file unusable. Shivering often persisted well into the recovery period and beginning stages of the neutral tub. A warmer temperature of 40 °C was also used in preliminary work, but subjects were uncomfortable and most could not remain in the water for the full 24 min period and all demonstrated higher elevations in core temperatures. Previous research has also found similar issue with cooler or warmer temperatures (Allison & Reger, 1998). Data were gathered over 24 min (6 min segments), because HRV measurement requires at least 5 min of steady continuous collection to accurately measure ANS activity. As our goals for this study were not only in assessment of responses over immersion time, but also at the initiation and removal from each immersion temperature, 6 min interval periods left us a margin of error for data cleaning and the ability to average segments from each immersion period. From a practical standpoint, each subject was studied for nearly 3 hr of continuous data recording and while a longer study time might have given somewhat different data, it is unlikely that the trends would have been substantively dissimilar.

## Conclusion

This is the first study examining aquatic immersion effects on age at different temperatures upon the ANS using HRV. Striking differences were seen between each of the three immersion periods. A pronounced increase in SVB balance accompanied warm water immersion and remained elevated through the final recovery period. This change was also joined by a reduction of both mean blood pressure and diastolic pressure although unlike SVB, blood pressure levels returned to baseline within the recovery period in our study. While core temperatures rose slightly during the warm water period, this change was minimal. Although the results appeared to have individual variation, results seen were significant. There may be clinical utility for the effects seen during warm water immersion.

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