FLOW State in Dancers:

Autonomic Regulation during Performance

A thesis submitted in partial fulfillment of the requirements

For the degree of Master of Science in Kinesiology

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Abstract

FLOW State in Dancers:
Autonomic Regulation During Performance

By

Kristin A. Jacobs
Master of Science in Kinesiology

Dancers are a unique group of athletes that self-report moderate to high levels of FLOW while engaging in their activity (Thomson & Jaque, 2011; Thomson & Jaque, 2012a; Thomson & Jaque, 2012b); this has shown to be indicative of a subjective and positive experience that lends to an intrinsic drive and dedication towards completing their activity (Csikszentmihalyi, 1990). Research relating autonomic regulation to FLOW state, especially during dance, is sparse. The objective of this study was to assess the attainment of FLOW during dance performance in relation to autonomic regulation using the Flow State Scale-2 (psychological assessment) and the Vivometrics Lifeshirt (physiological data collection) and Vivologics software. Autonomic parameters, such as heart rate variability (HRV), power spectral analysis of HRV (VLF, LF, HF, and LF:HF ratio), respiratory sinus arrhythmia (RSA), and pre-ejection period (PEP) were determined using the Vivologics software, Version 3.1 (Vivometrics, Inc., 2007). These parameters, in addition to the calculated variables of cardiac autonomic balance (CAB) and cardiac autonomic reactivity (CAR), were assessed during four different time periods in the performance...
process: baseline, pre-performance, performance and post-performance. Controlling for the presence of anxiety during the performance process, analyses of variance resulted in significant differences between dancers split into HI-FLOW and LO-FLOW groups with respect to LFn and LF:HF during performance, and the percent change in heart rate (HR) from pre-performance to performance. Using partial correlations (with anxiety as a covariate), significant relationships were found between mean global (total) FLOW, subscales Challenge Skill Balance (CSB), Activation Awareness merging (AA), and Autotelic Experience (AE) and the relative change in CAB from baseline to performance. The Sense of Control (SC) subscale was also partially correlated with the relative change in VLF and HR from pre-performance to performance. These results were indicative of heightened sympathetic modulation in dancers from baseline and pre-performance to performance. This withdrawal of vagal mediation with the increase in sympathetic activity into performance displayed a shift of cardiac autonomic balance (CAB) down the bivariate continuum that facilitated the FLOW experience in dancers.
Introduction

Dancers are unique athletes. Their sport demands elements of artistry and self-expression intertwined with physical athleticism. Dancers, as with many athletes, attempt to push their bodies and creativity above and beyond what is expected of their already challenging and harmonious movements during performance; this is the basis for which dancers may reach their flow state (Csikszentmihalyi, 1990). Csikszentmihalyi (1990) found that human beings experienced flow state (FLOW) when they were intrinsically driven and dedicated towards completing tasks and activities for their own benefit and well-being without extrinsic influence or reward. When the activity is thought to be meaningful and enjoyable and actions and movements are felt to be effortless, FLOW can be attained. The performance process an athlete or dancer goes through (i.e. physical warm-up, psychological preparation, environmental conditions, etc.) could potentially facilitate or hinder a dancer in reaching that optimal state during performance (Hefferon & Ollis, 2006; Jackson, 1995).

The autonomic nervous system (ANS) is made up of two primary branches, the parasympathetic system (“rest and digest”) and the sympathetic nervous system (“fight or flight”). The ANS has been shown to significantly regulate hemodynamics in humans (Jones, Shapiro, Keisling, Jordan, Shannon, Quaife, & Seals, 2001; Ogoh, Fisher, Dawson, White, Secher, & Raven, 2005). Generally, the sympathetic nervous system (SNS) activates under physical and/or psychological stress (as may be experienced during dance performance) and the parasympathetic nervous system (PNS) reciprocates action, and eventually withdrawals as the intensity of the stressor increases. This vagal mechanism during exercise modulates heart rate and blood pressure in order to maintain or regain homeostasis, by implementing quantitative measurements of the
psychophiological response and autonomic modulation during performance; this information may help dancers adjust elements of their preparation and execution to facilitate reaching FLOW, therefore making it an intrinsically satisfying and successful experience. This is the foundation for the present study.

Thomson and Jaque (2011) quantified and related psychophysiological states with autonomic regulation in performing artists, including dancers. The present study, under a similar experimental construct, will focus solely on dancers. With the use of the non-invasive Lifeshirt system (Vivometrics Inc., 2007), this study will collect continuous cardiac data on university-level dancers from California State University, Northridge throughout an entire performance day, assessing FLOW attainment and autonomic modulation from the start of the day, while in the wings preparing to perform, during performance, and during a recovery period. Commonly used autonomic markers (power spectral analysis of heart rate variability, respiratory sinus arrhythmia, pre-ejection period), as well as, calculations of cardiac autonomic balance (CAB) and cardiac autonomic reactivity (CAR) may provide a better understanding of the extent to which the autonomic nervous system regulates the psychophysiological state of FLOW during the entire performance process. The information obtained when researching such variables on this unique population of athletes could aid the dancer in controlling or altering their internal and external environment in order to facilitate their personal FLOW experience. Aside from assessing the dancer’s autonomic response to being “in the zone” during performance, the autonomic measures used in this study could also reveal potential pathological conditions, such as high blood pressure, diabetes, metabolic disorders, severe anxiety disorders, etc. (Cole, Blackstone, Pashkow, Snader, & Lauer, 1999), which could greatly affect the career or post-career of dancers.
FLOW State of Mind

FLOW, or feeling “in the zone”, is an intrinsically rewarding experience that encourages the individual to engage in the activity again (Engeser & Rheinberg, 2008; Jackson & Csikszentmihalyi, 1999). This is one of many reasons why FLOW exists in the performance of numerous active domains, including sports, performing arts, education and game playing (De Manzano, Theorell, Harmat, & Ullen, 2010; Engeser & Rheinberg, 2008; Jackson, Thomas, Marsh & Smethurst, 2001; Thomson & Jaque, 2011). The Csikszentmihalyi (1990) model of FLOW was extended to include nine constructs, or subscales, established by to explain this intrinsically rewarding and optimal mental state. (1) “Balance of Challenge and Skill” (CSB) is defined as the confidence that one’s own abilities can meet or overcome the demand. (2) “Activation-Awareness merging” (AA) occurs when the mind and movement meet and function as one, similar to automaticity. (3) “Clear Goals” (CG) is the knowledge and focus needed to reach the ideal end result and what is ultimately desired when doing the activity. (4) “Unambiguous Feedback” (UF) is continuous external and internal information that lets the performer/athlete know whether or not their movements and actions are desired. (5) “Concentration on Task at Hand” (CTH) is described as the full mental and physical absorption in the activity. (6) “Sense of Control” (SC) is a balance of control where the feeling that one cannot fail is prominent; one is a “master of fate”. (7) “Time Transformation” (TT) is defined as the total absorption in the task, a state that removes the awareness of time passing. (8) “Loss of Self-Consciousness” (LSC) occurs when distractions and/or awareness of one’s self does not break the focused state. The final subscale, (9) “Autotelic” (intrinsically rewarding) Experience (AE) is cultivated when
the activity is the reward in itself. Those individuals who approach life with such a philosophy are considered to have an “autotelic personality” (Csikszentmihalyi, 1990; Kawabata & Mallett, 2011).

FLOW is a subjective mental experience that is a process for each individual; different activities and different personal factors affect reaching this mental state. It is considered a positive experience that should bring about feelings of accomplishment and enjoyment (Csikszentmihalyi, 1990). Some people easily reach it and others never report achieving it (Jackson, 1995). Engeser and Rheinberg (2008) found the strongest factors relating to FLOW during performance were challenge-skill balance, concentration on task at hand, sense of control over the situation, and setting achievable goals. These findings were taken from an educational context where the subjects were monitored for FLOW experience during a semester long French class and a video game; in both cases, the controlled perceptions of FLOW were dependent upon how important the task was to the participants and how they perceived their own abilities at completing the tasks. Under this context, FLOW was more attainable when there was less importance placed on the task or the event. This has only shown to be somewhat compatible with findings of more active tasks. Challenge-skill balance, action-awareness merging and the autotelic experience are strong indicators of FLOW for dancers (Hefferon & Ollis, 2006; Thomson & Jaque, 2011); however, the more motivated and focused a dancer was on their performance (showing importance and intrinsic drive towards the task), the higher the likelihood of reporting FLOW (Hefferon & Ollis, 2006); this can be said for athletes of various sports as well (Jackson & Csikszentmihalyi, 1999; Jackson et al, 2001; Russell, 2001). These slight differences in findings show that the subjective elements that aid a person in achieving FLOW can differ in different fields of practice. It can be
achieved and experienced in many different areas of life (Ullen et al., 2012). Certain conditions of FLOW may be more influential in a solely cognitive field compared to when physical activity is involved.

Although the current study will not place focus on factors and conditions that directly affect a dancer’s FLOW experience, it is necessary to present and relate these topics to sport and alternative forms of performing arts for a better understanding of what might aid in cultivating, disrupting/preventing, and controlling the achievement of FLOW for dancers during performance. Csikszentmihalyi (1990) theorized that the facilitation of FLOW during performance for any task or activity consists of a balance between the perceived demands or challenges of the activity and the skill one possesses towards that activity. If the activity doesn’t provide enough challenge for the skill, the person might experience apathy or boredom; if the task is far too difficult (or perceived to be), the person might experience some form of anxiety. However, if there is balance between the two and the individual recognizes their ability to rise to the challenge, FLOW, in theory, can be attained and controlled. Kawabatta and Mallett (2011), confirmed a sequential organization of certain FLOW constituents that extends Csikszentmihalyi’s theory and could support the athlete in their self-efficacy and facilitate the FLOW experience. In their study of various competitive, non-competitive sports, and recreational activities, once an athlete had clear objectives established within their sport/activity (clear goals) and they felt any feedback could be easily interpreted and applied (unambiguous feedback), then the athlete would be more inclined to perceive that the demands of their activity would be met by their ability to perform (challenge-skill balance); with these three primary constituents met, FLOW would be facilitated and the other six constituents of FLOW would be experienced.
Overall preparedness (both mentally and physically) has shown to be important among athletes and performing artists when attaining FLOW. Russell (2001) interviewed 100 athletes from different team and individual sports about their FLOW experience during performance using a questionnaire based on the Flow State Scale. He found over half of his study participants (52.4%) reported mental preparation before competition to be the most profound element to facilitate entering FLOW; 48% of his participants reported physical preparedness to be the next most important element. Hefferon and Ollis (2006) findings were in congruence with Jackson and Czikszentmihalyi (1999). They showed how overall able and prepared the dancer was mentally and physically to perform, accompanied by the deeper intrinsic reward of just being able to dance and share expression (contextual motivation) dictated whether or not the dancer attained FLOW. During pre-performance preparation, an athlete must know how to balance the energy and technique necessary to meet the goals they have set (Jackson et al., 2001). Despite whether an athlete was a team player or solo performer, if the athlete felt confident, in control, and fully prepared for the event (mentally and physically), FLOW could be predicted during performance because the athlete could focus on actions during execution (Jackson, 1995; Russell, 2001).

The factors that facilitate FLOW during performance can just as easily disrupt or prevent a performer from achieving FLOW. Motivational drive, self-perception and arousal state were common threads among various active domains that could equally support or hinder the FLOW progression (Hefferon & Ollis, 2006; Jackson, 1995; Russell, 2001). In everyday life, including effort spent towards work and leisure, a purposeful, thought out and meticulous effort and drive has been positively associated with achieving FLOW (Ullen et al., 2012). Under a sporting context, Kowal and Fortier
(2000) made the distinction between situational motivation (the drive while actively participating in the sport/activity) and contextual motivation (motivation towards the sport/activity as a whole) in regards to facilitating FLOW among elite swimmers; they found a strong link with self-determination (personal reason) as a situational motivation for reaching FLOW. Contrary to Jackson and Czikszentmihalyi (1999), they did not report that swimmers found the act of participating in the sport of swimming, as a whole, to have any influence on their achievement of FLOW.

Lack of motivational drive has been associated with lack of challenge and lack of competence during performance. Ultimately, this can lead to a diminished desire to perform; this is either due to boredom from lack of effort or lack of importance to perform, or anxiety from lack of proficiency (Jackson, 1995). When an athlete or performer is overly self-critical, this psychological mindset can take the focus away from the set actions and goals and may interrupt and/or be detrimental to optimal performance (Jackson, 1995; Jackson et al., 2001; Hefferon & Ollis, 2006). Lack of motivation, lack of control and the inability to balance excitement towards performance (competitive or non-competitive) can hinder the process among athletes (Jackson, 1995; Russell, 2001).

Is FLOW a controllable mental state that an athlete or performer can make themselves reach? The level of skill in one’s task may be relative to the perception of FLOW controllability (Hefferon & Ollis, 2006; Jackson, 1995; Russell, 2001). In a contributory FLOW study performed by Jackson (1995), 27 elite competitive endurance athletes of various sports were interviewed about their control over reaching their FLOW state during performance. 79% of the athletes believed they could control their ability to enter into FLOW usually based on how prepared they felt for their specific event and/or the conditions leading into their event. Under a similar research construct, Russell (2001)
found only 64% of college athletes from his study felt FLOW was a state they could cultivate and facilitate based on preparedness and appropriate pre-performance choices, but was not something they could guarantee would be felt during performance despite preparation.

Dancers are unique athletes in that their performance does not just consist of the optimum execution of their trained skill. A dancer must simultaneously convey creativity, emotion, energy or a story to their observing audience. The transference of such affect while exhibiting physical control, continuity and fluidity of movement is what may set dancers apart from other athletes when attaining FLOW. There is limited empirical research collected on dancers and FLOW during performance, however Csikszentmihalyi (1990) and Hefferon and Ollis (2006) equated dance to “acting” or mimicking movements to convey emotional states. Postulating that dance is such an act, the ability to convey intended feelings and emotion to the audience could be a challenging event that the dancer would need to extend their abilities physically and mentally to overcome; the dancer must also give up the feeling of self in order to present the intended characterizations in the performance piece (loss of self-consciousness). In contrast, Thomson and Jaque (2012a) found this “mimicry”-type expression to be more associated with anxiety than FLOW in elite contemporary dancers where it was utilized as a coping mechanism for dancers with elevated anxiety.

**Autonomic Regulation during Dance and Exercise**

It is well known that at certain levels of intensity and duration, exercise poses a stress on the human body. The same can be said for dance as a physical activity. Contemporary dancers stay in or above their aerobic training zones of 60-90% their maximum heart rate longer in performance than in class and rehearsal (Guidetti,
Emerenziani, Gallotta, DaSilva, & Baldari, 2008; Wyon, Abt, Redding, Head, & Sharp, 2004; Wyon & Redding, 2005). Wyon et al. (2004) reported oxygen consumption levels between 45 and 55 mL.kg\(^{-1}\).min\(^{-1}\) during performance in both male and female contemporary dancers. Similar findings by Wyon and Redding (2005) demonstrated that dancers reach up to 95% their maximum heart rate during performance. Wyon et al. (2004) reported that modern dancers perform at high intensity levels for up to three minutes at a time or at a heart rate greater than 160 beats per minute for 7% of their performance time. The length of time they spend in these zones differs depending on performance and status (soloist, principal dancer, ensemble performer) (Guidetti et al., 2008).

Assessing only the physical activity component of dance performance, high levels of intensity in dance can induce a systemic stress response. There is not a copious amount of research on dance relative to autonomic functionality and regulation. The cardiorespiratory conditions will, therefore, need to be associated with the bipolar model of cardiovascular autonomic function relative to studies of different modalities of exercise and activities. During exercise of low to moderate intensity levels (50-60% peak oxygen uptake, VO\(_2\) \text{max})\), an increase in heart rate during exercise has shown to be due to the withdrawal, or significant decrease, in parasympathetic tone. As exercise intensity increases, sympathetic tone becomes more prominent (Robinson, Epstein, Beiser, & Braunwald, 1966). After maximal exercise, increased heart rate recovery to near resting levels was correlated with prominent parasympathetic reactivation and increased variance in heart rate, indicative of increased cardioprotection against cardiovascular disease, mortality, and sudden death (Cole et al., 1999; Tulppo, Makikallio, Seppanen, Laukkanen, & Huikuri, 1998).
The PNS and SNS regulate the certain hemodynamic measures by way of baroreflex receptors in the aortic arch and carotid sinuses in order to maintain homeostasis in the human body under different types of stress. Studies using autonomic blockades, such as beta-receptor blockades and muscarinic acetylcholine-receptor blockades have been shown to have a significant role in this regulation (Ogoh et al., 2005; Pickering, Gribbin, Petersen, Cunningham, & Sleight, 1972). Pickering et al. (1972) yielded evidence of significant and prevalent vagal modulation on baroreflex sensitivity during graded exercise (from rest to a workload of 32 watts) in different body orientations (supine and upright), showing an inverse and linear relationship between heart rate and arterial pressure under these conditions. They found that during graded exercise (without autonomic blockade), the baroreflex sensitivity decreased as exercise intensity increased due to normal vagal withdrawal during exercise; at heart rates of approximately 150 beats per minute (bpm) in study participants, they found the reflex response to be almost completely diminished and resulting in a rise in blood pressure. These findings were in line with an earlier study by Robinson et al. (1966) which reported the magnitude of change in mean arterial pressure (a marker of baroreceptor stimulation) was inversely related to HR changes during low-intensity exercise when compared to resting values under normal exercise conditions (40mmHg and 43 bpm, respectively). When a parasympathetic blockade was administered the values increased significantly (60mmHg and 52 bpm); these results coincided with values of HR and MAP at higher exercise intensities (without blockade). When a sympathetic efferent blockade was given, mean arterial pressure increased similar to that under normal conditions, but was not as affected as with the vagal blockade, and the HR change was blunted (40 mmHg and 15 bpm). This relationship demonstrates evidence of
parasympathetic dominance and cardiac control of heart rate, and ultimately blood pressure response to exercise.

**Physiological Markers of ANS Regulation**

Certain markers such as heart rate variability (HRV), spectral analysis of HRV, respiratory sinus arrhythmia (RSA), and the pre-ejection period (PEP) of the heart are used to demonstrate autonomic activity at rest and during various activities, especially exercise.

**Heart rate variability.** Heart rate variability (HRV) is a non-invasive measure and widely used critical marker for analyzing vagal activity. There are elements of both autonomic systems, however parasympathetic influence appears prominent, especially under resting and exercise recovery conditions (Blain, Meste, & Bermon, 2005a; Dewland, Androne, Lee, Lampert, & Katz, 2007; Robinson et al., 1966; Task Force of the European Society of Cardiology [TFESC], 1996). HRV is used to estimate PNS and SNS modulation to the heart. HRV can be described as the intrinsically spontaneous beat-to-beat oscillatory changes of heart period (time between each left ventricular contraction); rate of respiration also plays a role as a mediator of such variability (Pichon, De Bisschop, Roulaud, Denjean, & Papelier, 2004). Physiologically, these variations are primarily due to vagus nerve innervations of the Sino-Atrial (SA) node of the heart. The naturally occurring fluctuations of acetylcholine (parasympathetic neurotransmitter) transmission under low sympathetic conditions account for these spontaneous differences in rate (Dewland et al., 2007). HRV is not always affected by short term or low intensity exercise bouts, or exercise tolerance tests (i.e. VO2 max) in healthy adults (Dewland et al., 2007; Esco, Olson, Williford, Blessing, Shannon, & Grandjean, 2010). Leicht, Allen, and Hoey (2003) found that acute effects of moderate-
intensity exercise did not alter the parasympathetic modulation of cardiac activity. HRV, however, has shown to be influenced during short durations of high intensity activity (Blain et al., 2005a). HRV has also shown to play a significant role in displaying parasympathetic modulation and is complementary to post-exercise heart rate recovery. Buchheit and Gindre (2006) showed conflicting information in relation to the association of post-exercise HRR and HRV; acute short-term bouts of exercise were best monitored under indexes for HRR, and cardiorespiratory fitness was best represented with HRV. Despite the fact that both HRR and HRV are vagally controlled, they can each show effects of different exercise durations and intensities.

Studies have shown health implications of increased HRV and its spectral indices to be cardioprotective. In a study of long-distance runners and sedentary participants, there was no difference in LF power between the groups, but a significantly heightened HF power in the endurance athletes during a test of maximal oxygen consumption, indicating either slightly lower efferent sympathetic tone, or delayed withdrawal of parasympathetic mediation in the more endurance fit athletes (Shin, Minamitani, Onishi, Yamazaki, & Lee, 1997). Goldsmith, Bigger, Steinman, and Fleiss (1992) similarly found trained individuals to have an overall increased HF power throughout a 24-hour period, but these athletes conversely had increased LF, as well, compared to non-athletic individuals.

**Power spectral analysis of HRV.** Power spectral analysis (time and frequency domains) of HRV is a valuable way to analyze autonomic modulation and is regularly used to study the underlying physiological processes of cardiovascular control at rest and during exercise. HRV indices of high-frequency power (HF), low-frequency power (LF), very low-frequency power (VLF), Total Power (TP) and LF/HF ratio are most
widely used. The HF band (0.15 - 0.40 Hz) is used as an index to solely represent parasympathetic modulation to the SA node of the heart and incorporates respiratory influence (Pomeranz et al., 1985). The LF band (0.04 - 0.15 Hz) is controversial in research findings, however, it is usually referred to as an index for parasympathetic and sympathetic modulation (Goldsmith et al., 1992; Leicht et al., 2003) and shown to be a regulator of total peripheral resistance by way of baroreflex sensitivity (Pagani et al., 1986). LF has been used in previous studies as a marker for the sympathetic modulation (Shin et al., 1997), but has more often shown (in studies with vagal blockade) to also be influenced by parasympathetic modulation (Houle & Billman, 1999; Robinson et al., 1966) and demonstrate the capability to modulate autonomic activity via baroreceptor stimulation (Rahman, Pechnik, Gross, Sewell, & Goldstein, 2011). VLF band (0.00 – 0.04 Hz) has been shown to be representative of peripheral chemoreceptor sensitivity (Ponikowski et al., 1996). LF/HF ratio is a common index used to demonstrate sympathovagal balance (Robinson et al., 1966).

The bipolar model of cardiac regulation uses the frequency band components present in HRV. During an orthostatic tilt table experiment with a healthy cohort of subjects, Pagani et al., (1986) found a large increase in LF power (lnLF: $M = 89.5$, $SD = 1.4$ during tilt and $M = 62.0$, $SD = 5.0$, $p<0.05$ during rest) and marked decrease in HF power (lnHF: $M = 6.0$, $SD = 0.5$ during tilt and $M = 28.5$, $SD = 3.3$, $p<0.05$) and did not find the LF/HF ratio to change significantly, displaying a reciprocal adjustment between the two autonomic tones. During such postural changes, the LF marker coincided with marked increases in systolic and diastolic blood pressure and arterial pressure variability. In the same study, when a pharmacologic sympathetic efferent blockade was introduced to the tilt experiment, LF/HF remained decreased ($M = 3.78$, $SD = 0.93$, $p<0.05$), which
was similar to the controlled resting values of these subjects without tilt, and compared to the LF/HF values found without the beta-blocker during tilt ($M = 20.79$, $SD = 3.68$, $p<0.05$); this is indicative of a shift in sympathovagal balance towards heightened baroreceptor sensitivity and accentuated sympathetic tone and attenuated parasympathetic tone during such postural changes.

In contrast to many studies, Rahman et al. (2011) provided evidence describing the limitations of power spectral analysis of HRV to display only sympathetic involvement in cardiac regulation, and suggested that LF power was more a measure of baroreceptor sensitivity to both parasympathetic and sympathetic outflow. They reported a positive relationship between the LF and HF components of HRV and baroreflex sensitivity (measured by calculated baroreflex-cardiovagal gain) during rest in both control subjects and patients with autonomic and neurological disease ($r = 0.68$, $p < 0.01$ and $r = 0.64$, $p < 0.01$, respectively). In their study, the Valsalva maneuver caused an increase in the LF band relative to an increase in baroreflex sensitivity ($r=0.61$, $p < 0.01$), showing vagal influence during this stress inducing maneuver. Supporting their findings, they generally found higher mean values of LF during the Valsalva maneuver in patients with normal baroreflex function versus those patients with low baroreceptor sensitivity ($p<0.01$).

The very low frequency of oscillations within the R-R interval have shown in earlier studies to be hard to detect due to excessive artifact, or noise, found within R-R interval tracings (Yamamoto, Hughson, & Peterson, 1991), especially during human movement. Ponikowski et al. (1996), studied chemoreceptor sensitivity under conditions of hypoxia (decreased oxygen) and hyperoxia (excess, 60%, oxygen) in patients with congestive heart failure. They found a relationship between increased VLF power
fluctuations and heightened peripheral chemosensitivity under hypoxic conditions in these patients, however, found significant diminished VLF oscillations when patients were given an excess of oxygen (hyperoxic: \( r = 0.97, p = 0.0014 \)). VLF oscillatory fluctuations can be indicative of greater imbalance of the autonomic nervous system and heightened chemoreceptor sensitivity. The study suggests that increased chemoreceptor sensitivity could cause sympathetic over-dominance, a decrease in baroreflex sensitivity (LF), and peaks of the VLF oscillations. Perini, Orizio, Baselli, Cerutti, and Veicsteinas (1990) demonstrated similar findings under graded exercise conditions in healthy, untrained and sedentary men. As exercise intensity increased, these researchers found increased sympathetic modulation (beginning at approximately 30% VO\(_2\)max) with a relative increase in VLF, accompanied by a decrease in LF. These alterations of VLF (and LF) were reported to be due to changes in respiration when exercise levels were greater than 30% VO\(_2\)max.

**Respiratory sinus arrhythmia.** Respiration and circulation are significantly controlled by the autonomic nervous system; respiratory sinus arrhythmia (RSA) establishes cooperation between these two functions. Used as a significant marker of autonomic regulation, RSA is the synchronization of breathing with the beat-to-beat fluctuations of the heart rate. Synchronicity has shown spontaneous beats of the heart to shorten during inspiration and lengthen during expiration (Blain, Meste, Bouchard, & Bermon, 2005b). When analyzing RSA, HRV frequency analysis (measured in Hz) is used because of its dependency on the beat-to-beat frequency of the heart rate. In exercise testing, such as maximal oxygen consumption tests (VO\(_2\) Max), a consistent display of the variable timing and frequency of the sino-atrial (SA) node coincide with the frequency of respiration (Blain et al., 2005a; Blain et al., 2005b). Even though there is an
inadequate amount of research reporting the effects of high intensity exercise on RSA because of the difficulty of measuring respiratory patterns during maximal exercise, Blain et al. (2005a) found HRV is mediated by RSA at high intensities during short term bouts of exercise.

**Pre-ejection period.** PEP is a measure of the total time period from the start of electrical stimulation of the cardiac ventricles (ventricular depolarization) from the atrio-ventricular node (AV node) up to the moment of mechanical contraction of the left ventricle. The end of the pre-ejection period is distinguished by the opening of the aortic valve just before blood from the left ventricle is ejected out. PEP is an autonomic marker for sympathetic activity due to its responsiveness to sympathetic catecholamine levels (namely, adrenaline and noradrenaline). A shortened PEP is equivalent to an increase in contractility (Newlin & Levenson, 1979). In a study comparing sedentary, physically active, and athletically trained participants at rest, PEP was unexpectedly and markedly shorter in the athletes compared to the sedentary participants ($M = 120.5, SD = 2.7$ msec and $M = 134.6, SD = 2.7$ msec, respectively). The end-diastolic volume was not measured, however, to observe the functionality of such a shortened pre-ejection time (Winters, Leaman, & Anderson, 1973). Conversely, Gollan, Kizakevich, and McDermott (1978) demonstrated an immediate decrease in PEP due to the intensifying workloads of a six stage Bruce protocol exercise test on a treadmill. An immediate drop by approximately 26% (24 ms) from rest to the first exercise workload was observed, and a further decrease by 58% (compared to the resting measure) by the fourth stage; the temporal decrease of 4 ms continued at each remaining stage of the test. This decrease in pre-ejection time is indicative of increased sympathetic effects at higher exercise workloads.
FLOW and ANS Regulation in Dancers

FLOW, relative to many different activities, should be a pleasurable experience driven by the intrinsic desire to perform a task or activity for the sake of doing it, in other words, for the autotelic experience (Csikszentmihalyi, 1990). It might be expected that autonomic activity during FLOW would be different from that of an opposing state of mind, and more mediated by the “rest and digest” branch of the ANS. FLOW, however, is a subjective and individual experience, and cardiac measures need to be further assessed. The psychophysiological responses that occur when attaining FLOW during sports or arts performance have been minimally researched, and therefore, are somewhat of a mystery in many domains of physical activity. De Manzano et al., (2010) and Thomson and Jaque (2011) were similar in their findings among studies of performing artists. A predominance of sympathetic tone was found in both studies where the artists self-reported entering the FLOW state while in performance mode. In a separate study of highly trained dancers by Thomson and Jaque (2012a), state and dispositional FLOW was reached by 75.3% of the participants in performance, even though over 20% of the dancers scored high for anxiety. With increased sympathetic markers indicating a shift in sympathovagal balance and regulation, the achievement of FLOW may not be related to increased mental stress, but could be a phenomenon all its own. It is, therefore, proposed that performance related changes in autonomic nervous system balance and regulation will be related to FLOW state during performance. Based on the research done by Thomson and Jaque (2011), it is also proposed that performance related changes in ANS balance and regulation will be related to the subscales of FLOW during performance.
Methods

Participants

17 healthy, university-level dancers (12 female, 5 male) were randomly selected or volunteered for this IRB-approved, cross-sectional study. They were required to have at least five years of dance training and at least one year of performance experience, be a student (undergraduate or graduate) at California State University, Northridge in the Kinesiology/Dance department, and be a performer in the dance production show put on each semester, *Kinesis* (Fall semester) and *Collaboratoria* (Spring semester). Before the study began, each dancer read and signed the informed consent. Their demographic information was then collected, including age, gender, height and weight. Demographics were collected for reference to the sample of dancers participating in the study, and these measures were not used in the analyses; ethnicity and race were not demographic variables proposed to influence the goals of the current study and were not collected.

Psychological Instruments

With the exception of the FSS-2, each participant was required to complete the Psychophysiological Study of Performing Artists and Athletes Participant Packet provided by the researchers prior to their day of performance. The packet consisted of various psychometric instruments and self-report questionnaires. The psychometric instruments relevant to the current study are as follows:

**Flow State Scale-2 (FSS-2) (Jackson & Eklund, 2002).** A 36-item, self-report instrument created by Susan A. Jackson and Robert C. Eklund that was used as a multidimensional assessment of FLOW. In this study, it was used to evaluate the flow experience within the dance domain. The FSS-2 was administered separate from the packet, and immediately after the dancer’s final performance piece. The FSS-2 was used
to determine the dancer’s experience of FLOW within that particular on-stage
performance (dance domain) in regards to the first order nine FLOW subscales and
global factor model. The flow state assessment was based on a 5-point Likert rating scale
for all subscales and global factors (1 = low FLOW experience, 5= high FLOW
experience).

**Beck Anxiety Inventory (BAI-II) – (Beck, Epstein, Brown, & Steer, 1988).**
The BAI-II is a 21 question, self-report inventory that evaluates the severity of anxiety;
more specifically, it evaluates the cognitive and somatic components of anxiety and the
panic related symptoms that the participant has experienced over the previous week.
Participants rank the items from 0-3 (0 = not at all, 3 = severely). Minimal levels of
anxiety are indicated with a score from 0-7; mild anxiety indicated with a score from 8-15;
and clinical disorder indicated by scores of 16-25 and 26-63 for moderate anxiety
and severe anxiety, respectively. In the current study, the BAI was administered prior to
performance day.

**Physiological Instrument**

**Lifeshirt System (Vivometrics Inc., 2007).** The Lifeshirt is a vest designed to
be worn for the collection of various quantitative physiological data during various
activities, including exercise. Continuous data from respiration, ECG, pulse oximetry,
blood pressure and body positioning can simultaneously be collected and stored. For the
current study, the Lifeshirt system was used to provide a non-invasive analysis of
breathing patterns and cardiac changes (via ECG) in order to assess autonomic
functionality of dancers during performance. Lifeshirt and Vivometrics systems have
been validated for accuracy during rest and exercise for detecting R-R interval and
interval timing (Heilman & Porges, 2007).
The VivoLogics software (Vivometrics Inc., 2007) is the data processing software that accompanies the Vivometrics Lifeshirt system. For ECG and R-R interval information, three electrodes (ClearTrace adult ECG Electrode, ConMed Corporation, NY, Ref # 2700-005) were placed on the participant’s upper chest (chest leads 1 and 2 were placed at the center of the right and left pectoralis muscles, respectively) and the third electrode was placed at the margin of the external oblique of the lower left abdomen to establish Lead II channel of the ECG (sampling rate of 200 Hz). The chest band was secured around the ribcage to measure chest circumference changes and monitor respiration. The respiratory component of the Lifeshirt, the Fixed Volume Least Squares algorithm, was individually calibrated to the participant. Alternating twice between the seated and standing positions for calibration accuracy, each participant hyperventilated a total of seven times into the Vivometrics 800cc fixed volume calibration bag (part #910-0185-000). The postural changes allowed for the rib cage and abdomen contributions with each breath to be acquired during calibration. An accelerometer, located on the anterior of the Lifeshirt vest, was used to monitor motion and postural changes during data acquisition. This information, along with date and time, was synchronized with the dancer’s log sheet.

**Protocol**

Prior to the study day, each dancer was required to fill out the BAI (as part of Psychophysiological Study of Performing Artists and Athletes Participant Packet). On the performance day (study day), prior to the start of any study measurements, each dancer was properly fitted in the Vivometrics Lifeshirt for physiological monitoring. Once date, time, and ECG signal were verified and calibration of the recorder was complete, data was immediately collected. The data was continually collected and saved
in the recorder on a SanDisk Ultra II, 1.0 GB scandisk (memory card). The Lifeshirt recorder was placed in a belted pouch secured to the dancer’s waist. Without altering the functionality of the Lifeshirt, the dancers adapted the vest into their costuming so as not to interfere with performance execution. The dancers were instructed to progress through their day (the dress rehearsal and performance periods) as normally as possible.

Testing began with an uninterrupted seven minute rest period where the dancer lay supine in a quiet environment for the collection of baseline measures. The dancers were observed and any movements or behaviors that may correspond with changes in their psychological or physiological state (i.e., waiting in wings to perform, costume changes, ingestion of stimulants, emotional or behavioral changes, discussions with peers, etc.) were marked on the Vivometrics data recording using an event marker, as well as documented in detail at the time of occurrence on a log sheet throughout the entire study day. Once baseline measures were collected, the dancer proceeded through the dress rehearsal period (acclimating the dancer to the Lifeshirt within his/her actual performance piece) and performance period (the show). Data collected during dress rehearsal was not used for the current study. Immediately following the dancer’s final performance of the show, he/she was instructed to complete the FSS-2 in response to their stage experience. Completion of the study was preceded by a final 7 minute rest period, under the same conditions as the initial rest period. The duration of the study was 4-10 hours.

**Data analysis of psychological measures: FSS-2, BAI**

**FLOW State Scale.** The raw data scores were tabulated for each subscale and global value for the FSS-2 and were entered, for each dancer, directly into SPSS for statistical analysis. Totals for each subscale and global value were calculated in SPSS as
a separate variable. The mean totals were then normalized to the distribution by taking
the square root of those values.

**Beck Anxiety Inventory.** The raw data scores from the Beck Anxiety Inventory
were tabulated and totaled before being entered into SPSS for statistical analysis. Once in
SPSS, the square root was taken of the total mean scores in order to normalize the
distribution of the values.

**Data analysis of physiological data & CAB and CAR calculation**

Raw data collected from the Lifeshirt was stored on a data memory card in the
Lifeshirt recorder and transmitted in a raw wave form format to the VivoLogic Software,
Version 3.1 (Vivometrics, Inc., 2007) using the data transfer conduit. Data was saved as
a “.viv” (file extension given to the raw data file). Each file was saved with date and a
coded participant number for the study. Once downloaded into the study database, the
raw data file was smoothed and filtered. After running the R-wave picker (VivoLogic
algorithm of recomputed R-wave placement) and trends were made within the program,
the raw R-R intervals were edited and interpreted in the “ECG Artifact Marking View”.
The R-R intervals were smoothed so that any residual muscular noise or ectopy (any non-
sinus beat) was marked as artifact. If the R-wave was missing or interpreted in error, an
R-wave was manually corrected. The signal was then considered to be normal, and to
provide normal-to-normal R-R intervals. The subsequent smoothing technique was
executed under the “TCG Cleaning view”. Thoracocardiography, or inductance
cardiography, is a technique used to monitor the mechanical cardiac and ventricular
function; PEP data was assessed and cleaned under this view.

The independent variable in this study was the designated time periods during the
performance day: Baseline (5 minutes at baseline during the 7-minute initial rest period),
pre-performance, (3-minutes in the wings immediately before performance), performance (dancer’s active on-stage performance), and post-performance (final 5-minutes of the recovery rest period). In order to extract the time segments of data needed for analysis, reference to the dancer’s performance log-sheet was necessary for the exact time frame of each time segment; the accelerometer and steps field within the software aided in determining body positioning and movement. The mean and standard deviation values for PEP during each time segment were extracted from the smoothed file. No interpolation of data was necessary for PEP information.

VivoLogics Fast Fourier Technique (FFT) was designed within the software to accurately analyze spectral components of heart rate variability for time segments longer than 60 seconds. Interpolation of the R-R intervals was necessary to compute both time and frequency components of the HRV power spectrum within the algorithm of the software. The mean statistical values for HRV and HRV indices were extracted from the smoothed data file for each time segment; these values for each time segment of the performance day were exported into an Excel spreadsheet from the “CSUN 007” view.

The primary cardiovascular measures of sympathetic and parasympathetic cardiac control extracted from the Lifeshirt recordings in the VivoLogic software were spectral analysis of HRV (raw values of VLF, LF, and HF, LF/HF, and LF\textsubscript{n} and HF\textsubscript{n}), RSA, and PEP. The raw statistical means of VLF, LF, HF, RSA and PEP were converted to the natural log (ln) to normalize and stabilize the distribution of the values. Cardiac autonomic balance (CAB) and cardiac autonomic reactivity (CAR) were also calculated (see below for calculations) for each participant at each time segment of the study. The mean values and calculations for all the autonomic parameters were plugged into the statistical analysis software.
**Calculation of CAB and CAR:** Bernston, Norman, Hawkley, and Cacioppo (2008) formulated a two-dimensional model of cardiac “autonomic space” of regulation; the two autonomic regulatory models associated with “autonomic space” that were applied to the current study are cardiac autonomic balance (CAB) and cardiac autonomic reactivity (CAR). These measures were derived as a method to further analyze coupled and uncoupled activation of the ANS and PNS during psychophysiological states and activities.

CAB is defined as the measure of autonomic balance of SNS and PNS reciprocation and calculated from the difference between the normalized values of HF and PEP \( \text{CAB} = \text{HFz} - (\text{-PEPz}) \); high CAB values are representative of greater parasympathetic control and lower sympathetic control (based on a higher HF component and longer PEP measurements, respectively). CAB was shown in the study to be inversely related to LF/HF and heart rate, displaying strong parasympathetic control. CAR is a measure representing autonomic coactivation or coinhibition. It is calculated as the sum of the normalized values of HF and PEP \( \text{CAR} = \text{HFz} + (\text{-PEPz}) \). Since CAR is representative of coactivation of the two autonomic branches, there remains to be a strong indication of PNS influence, along with SNS control. High CAR values indicate high parasympathetic and sympathetic tone, allowing for lower values of LF/HF.

Raw HF and PEP values were normalized in order to adjust the values into a common scale. Normalized HF and PEP values were then converted to z-scores before calculating CAB and CAR in order to transform the normalized values in the distribution to the specific standard deviation values above or below the mean of the distribution. Once z-scores were calculated, CAB and CAR were calculated in the statistical software.
Statistical analysis

The statistical analyses were done using the IBM SPSS Statistics Data Editor, Version 22, 32-bit edition (1989, 2013). Logarithmic transformations of VLF, LF, and HF band powers, PEP, and RSA were used to normalize the distribution of this data. Normalized total mean FSS scores were used for all correlational analyses. For the calculation and analysis of CAB and CAR, raw HF and PEP values were normalized in order to adjust the values into a common scale. Normalized HF and PEP values were then converted to z-scores before calculating CAB and CAR in order to transform the normalized values in the distribution to the specific standard deviation values above or below the mean of the distribution. Calculations of CAB and CAR were done in SPSS.

The means of the spectral analysis of HRV (all power bands), PEP, RSA, CAB, and CAR were analyzed among the four independent time periods of performance (baseline, pre-performance, performance, and post-performance) among the FLOW groups using Independent sample t-tests, One-way Repeated Measures analysis of variance, and Correlation analyses. To control for the possible effects of anxiety, MANCOVA with Bonferroni post hoc correction was then run to test the mean differences within the HI-FLOW and LO-FLOW groups between the autonomic performance parameters. Partial correlations were run to test for any relationships that exist between the dependent variables in relation to the four time periods of performance.

FSS mean scores for each subscale were normalized by square root (except the subscale of TT – Time Transformation, which was already normally distributed). Repeated measures MANCOVA with Bonferroni post hoc correction and partial correlation analyses were used to analyze differences between the means and relationships between the FLOW subscales and autonomic parameters at each of the
performance time periods, respectively. Anxiety scores were used as the covariate measure.

Normalized total means obtained from the Beck Anxiety Inventory were used for the covariate to control for the presence of any pathological anxiety for all associated analyses. The Pearson product-moment correlation coefficient, \( r \), was representative of the strength of any existing relationships for all correlation analyses. A probability less than alpha level of 0.05 for significance was used for all statistical analyses.
Results

Anthropometric and descriptive statistics for global (total) FLOW and FLOW subscale scores for all participants in the study are displayed in Table 1. All dancers (N = 17) reported moderate to high state FLOW responses to their performance on the study day. State FLOW responses ranged from scores 3-5 (moderate - high) for all subscales and overall (global) FLOW. A median split of the total mean FSS-2 scores into two groups representing HI-FLOW (n = 9, Mdn ≥ 4.28), and LO-FLOW (n = 8, Mdn < 4.28) were utilized for all repeated measures analyses. Descriptive statistics for mean scores and

| TABLE 1. Anthropometric characteristics and Descriptive Statistics (FSS-2 mean scores, BAI scores) |
|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
|                                              | Total (N=17)                                  | LO-FLOW group (n=8)                           | HI-FLOW group (n=9)                           |
| Age (yr)                                      | 23.00 (.66)                                  | 23.88 (3.64)                                 | 22.22 (1.30)                                 |
| Height (in)                                   | 65.94 (.82)                                  | 66.94 (2.83)                                 | 65.06 (3.71)                                 |
| Weight (lbs)                                  | 136.54 (5.17)                                | 139.06 (23.58)                               | 134.30 (20.21)                               |
| BAI                                           | 12.38 (13.02)                                | 11.75 (12.78)                                | 12.94 (13.97)                                |

Global FLOW 4.24 (.54) 3.80 (.41) 4.62 (.30)*
CSB 4.45 (.60) 3.99 (.53) 4.89 (.18)*
AA 4.24 (.96) 3.56 (1.02) 4.83 (.28)*
CG 4.60 (.43) 4.28 (.43) 4.89 (.13)*
UF 4.46 (.52) 4.13 (.44) 4.75 (.40)*
CTH 4.40 (.75) 3.84 (.73) 4.89 (.25)*
SC 4.31 (.76) 3.66 (.58) 4.89 (.25)*
TT 3.47 (1.09) 3.53 (.65) 3.42 (1.41)
LSC 3.72 (1.26) 3.22 (1.11) 4.17 (1.27)
AE 4.51 (.75) 4.06 (.90) 4.91 (1.18)*

Note: MANCOVA (BAI anxiety covariates) comparison of mean scores showing significant group differences between HI and LO-FLOW groups. Values are reported Mean (SD), BAI scoring: Anxiety scoring 0-7 (minimal), 8-15 (mild), 16-25 (moderate), 26-63 (severe). State FLOW scores from FSS-2 inventory: Scoring 1-2 (low), 3-4 (moderate), 4-5 (high).

*denotes p<.05 - Level of significance used to assess differences between HI-FLOW and LO-FLOW groups for subscales.

Abbreviation: BAI - Beck Anxiety Inventory, CSB - Challenge-Skill Balance, AA - Awareness Activation, CG - Clear Goals, UF - Unambiguous Feedback, CTH - Concentration on Task at Hand, SC - Sense of Control, TT - Time Transformation, LSC - Loss of Self-Consciousness, AE - Autotelic Experience
standard deviations of all ANS regulation parameters for each measured time period of the performance day (baseline, pre-performance, performance, and post-performance) are displayed in Table 2.

<table>
<thead>
<tr>
<th>TABLE 2. Mean (SD) Descriptive Statistics for the ANS markers (N = 17)</th>
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<tbody>
<tr>
<td>Baseline</td>
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<tr>
<td>HF (ms²)</td>
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<td>HFn</td>
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<td>lnHF</td>
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<tr>
<td>LF (ms²)</td>
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<tr>
<td>LFn</td>
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<tr>
<td>lnLF</td>
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<tr>
<td>VLF (ms²)</td>
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<tr>
<td>lnVLF</td>
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<tr>
<td>LF:HF</td>
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<tr>
<td>RSA</td>
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<tr>
<td>lnRSA</td>
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<tr>
<td>PEP (ms)</td>
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<tr>
<td>lnPEP</td>
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<tr>
<td>HR (bpm)</td>
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</table>

Values are reported Mean (SD).

**ANS Regulation and Total Flow.** Initial independent T-tests and repeated measures testing showed no significant differences between the means of the HI-FLOW and LO-FLOW groups within the raw scores of the ANS parameters (lnVLF, lnLF, lnHF, LFn, HFn, LF:HF, lnPEP, lnRSA) and the percent changes of these ANS parameters during the four measured performance time periods (baseline, pre-performance, performance, and recovery). Initial correlation analyses showed the percentage of change in CAB (cardiac autonomic balance) from baseline to performance was statistically significant and positively related \( r(17) = 0.497, p=0.043 \) to the normalized FLOW total mean score. Figures 1-4 display the dispersion of autonomic regulation along the bivariate, CAB and CAR, continuum at all four study time periods.
Partial correlation analyses found a positive relationship, similar to initial correlational findings, between change in CAB (cardiac autonomic balance) and total FLOW from baseline to performance \[ r(14) = 0.510, p = 0.044 \]; FLOW total mean score and LFn were inversely correlated \[ r(14) = -0.562, p = 0.023 \], and an inverse relative tendency of FLOW and LF:HF ratio \[ r (14) = -0.494, p = 0.052 \] during performance were found when anxiety was controlled for.

Figure 1. BASELINE distribution of ANS regulation among dancers (N = 17) within two-dimensional "Autonomic Space" model. Baseline performance measures were collected during 5-minutes supine rest at the beginning of the performance day.
A series of one-way repeated measures MANCOVAs were conducted to analyze the variance in means and influence of the four performance time periods on the raw ANS of anxiety. In the first repeated measures analysis, a significant multivariate main effect with FLOW for these parameters [Wilks’ λ (2, 3.92) = .624, p=.047, partial \( \eta^2 = .376 \)]. There was between-subject effects found with LF:HF ratio \( (F(1,13) = 6.140, p = .027, \text{ partial } \eta^2 = .305) \) and LFn \( (F(1,13) = 7.44, p = .016, \text{ partial } \eta^2 = .347) \) between the HI and
LO-FLOW groups during performance. Pairwise comparisons showed the ratio of LF:HF during the performance \((p = .027)\) was higher in the LO-FLOW group \((M = 7.55, SD = 4.05)\) than in the HI-FLOW group \((m = 3.49, SD = 2.34)\). LFn during performance \((p = .016)\) was also higher in the LO-FLOW group \((M = .54, SD = .16)\) compared to the HI-FLOW group \((M = .33, SD = .15)\).
A significant multivariate main effect was found between the mean differences of the HI and LO-FLOW groups and performance time periods, Wilks’ $\lambda (11,45,82) = .008$, $p = .001$, partial $\eta^2 = .992$; as well as an effect found for the FLOW groups and the covariate of anxiety, Wilks’ $\lambda (4,5.77) = .323$, $p = .009$, partial $\eta^2 = .677$. All within-subject interactions were non-significant. Multivariate test of within-subject effects

![Figure 4](image_url)

**Figure 4.** POST-PERFORMANCE distribution of ANS regulation among dancers ($N = 17$) within two-dimensional "Autonomic Space" model. Post-performance measures were collected for 5-minutes of supine rest at end of performance day.
showed significant differences in the group means of the ANS regulation parameters (LFn, HFn, CAB, and CAR), Wilks λ (12, 5.71) = .260, p = .00, partial η² = .361. Univariate results for this relationship demonstrated a significant effect for LFn (F(3, 103.48) = 3.223, p = .032, partial η² = .187), and secondary effect of HFn with anxiety (covariate) (F(1, 4) = 4.595, p = .05, partial η² = .247) between the FLOW groups; non-significant results were found for the raw scores of CAB and CAR [F(3, 103.48) = .889, p = .455, partial η² = .060 and F(3, 103.48)= .765, p = .520, partial η² = .052, respectively.]

The post hoc Bonferroni adjustment for significance displayed the following significant results based on the pairwise comparisons: LFn decreased from baseline to pre-performance (p = .000), increased from pre-performance to performance (p=.001), and increased from pre-performance to post-performance (p = .001); HFn increased from baseline to pre-performance (p=.000), increased from baseline to performance (p=.000), decreased from pre-performance to post-performance (p=.002), and decreased from performance to post-performance (p=.001).

With anxiety as a covariate, the final analysis of variance was conducted to evaluate the influence of the four performance time periods and variance in the means of the percent change of the ANS regulation parameters between the HI-FLOW and LO-FLOW groups along the performance time periods. Initially, it revealed a non-significant multivariate main effect for FLOW [Wilks’ λ = .277, F (10, 5) = 1.302, p = .406]. When the analyses were re-run using a fewer dependent variables, a significant main effect was found between the FLOW groups [Wilks’ λ = .573, F (2, 13) = 4.851, p = .027]. Univariate analyses revealed significant differences with between-subject effects for percent change in HR [F(1, 13) = 8.960, p = .010, partial η² = .390] and percent change in
LFn ($F(1, 13) = 4.91, p = .044, \eta^2 = .259$) from pre-performance to performance among the FLOW groups. Bonferroni adjustments for significance showed a greater change in HR from pre-performance to performance in the HI-FLOW group ($M = 48.39, SD = 14.09$) compared to that of the LO-FLOW group ($M = 23.35, SD = 19.49$), and greater change of LFn from pre-performance to performance in the HI-FLOW group ($M = -46.35, SD = 25.51$) compared to that of the LO-FLOW group ($M = -17.98, SD = 25.70$).

**ANS Regulation and FLOW subscales.** Partial Correlation analyses were run to find existing relationships between the FLOW subscales and ANS regulation parameters during each performance time period while controlling for the influence of anxiety (using normalized scores from the BAI). Significant relationships with the subscale SC (Sense of Control) were found. Significant results for the raw scores of the ANS parameters were as follows: SC (Sense of Control) was inversely related to lnVLF during performance [$r(14) = -.539, p = .031$]. A close, but insignificant negative correlation of SC with CAB during performance was also found [$r(14) = -.483, p = .058$]. From baseline to performance SC was positively related to the percent change in heart rate (HR) [$r(14) = .504, p = .047$]. From pre-performance to performance, a positive relationship was seen with the percent change in HR [$r(14) = .684, p = .004$] and a very close, but insignificant, negative correlation existed with the percent change of VLF [$r(14) = -.496, p = .051$].

Table 3 displays the partial correlations of global FLOW and the nine FLOW subscales with the relative changes in the specific ANS parameters for the dancers from baseline to performance. Significant partial correlations were found with other subscales of FLOW as well. The percent change in CAB from baseline to performance was positively related to CSB (Challenge-Skill Balance) [$r(14) = .526, p = .036$], AA.
**TABLE 3.** Partial Correlations for Percent Changes in ANS Regulation from Baseline to Performance, and FSS-2 Scores for Global FLOW and FLOW subscales

<table>
<thead>
<tr>
<th>Measure</th>
<th>1</th>
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<tbody>
<tr>
<td>1. Global FLOW</td>
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<td>2. CSB</td>
<td>.917*</td>
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<td>3. AA</td>
<td>.832*</td>
<td>.796*</td>
<td>1.00</td>
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<td>4. CG</td>
<td>.648*</td>
<td>.763*</td>
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**Abbreviation:** CSB - Challenge-Skill Balance, AA - Awareness Activation, CG - Clear Goals, UF - Unambiguous Feedback, CTH - Concentration on Task at Hand, SC - Sense of Control, TT - Time Transformation, LSC - Loss of Self-Consciousness, AE - Autotelic Experience; CAB - Cardiac Autonomic Balance, CAR - Cardiac Autonomic Reactivity, HR - Heart Rate, VLF - Very Low Frequency power, RSA - Respiratory Sinus Arrhythmia

Partially Correlated with mean BAI score as covariate

*p < .05, **p < .10 denotes level of significance
(Activation Awareness) \( r(14)=.586, p = .017 \], and AE (Autotelic Experience) \( r(14)=.642, p=.007 \]; LSC (Loss of Self-Consciousness) was inversely related to the percent change in LF:HF \( r(14) = - .591, p = .016 \] and positively correlated to the percent change in RSA from baseline to performance \( r(14)=.588, p = .017 \]. From pre-

to performance, the percent HR change was significantly related to CG (Clear Goals) \( r(14) = .494, p = .052 \).

To assess the differences in mean scores of the FLOW subscales between HI-
FLOW and LO-FLOW groups, an analysis of variance was run. A significant multivariate main effect was found between the HI and LO-FLOW groups for the nine FLOW subscales, Wilks’ \( \lambda (8, 5.56) = .136, p = .018 \), partial \( \eta^2 = .864 \), with anxiety controlled for. No significance was found for the between-subject effects of LSC \( F(1, 7) = 2.232, p = .157 \), partial \( \eta^2 = .138 \) and TT \( F(1, 5) = .051, p = .825 \), partial \( \eta^2 = .004 \). Significant differences were found between the means of HI- and LO-FLOW groups for the remaining FLOW subscales: SC \( F(1, 7) =42.54, p =.000 \), partial \( \eta^2 =.752 \], CTH \( F(1, 7) =13.83, p =.002 \), partial \( \eta^2 =.497 \], UF \( F(1, 7) =8.86, p =.010 \), partial \( \eta^2 =.388 \], CG \( F(1, 7) = 15.16, p = .002 \), partial \( \eta^2 = .520 \], AA \( F(1, 7) = 10.41, p = .006 \), partial \( \eta^2 = .426 \], and CSB \( F(1, 7) =21.04, p =.000 \), partial \( \eta^2 =.600 \].
Discussion

The current study sought to investigate the performance related changes in autonomic nervous system regulation and how this response was related to global (total) state FLOW and the FLOW subscales during performance in dancers. Overall, dancers self-reported relatively high levels of global FLOW during their dance performance in a semester show for California State University, Northridge ($Mdn = 4.28$, $M = 4.24$, $SD = .54$). These results were slightly higher, yet in line, with Thomson and Jaque (2012a). The median split of the sample of dancers based on their elevated FLOW scores lent the LO-FLOW group to represent moderate to high levels of FLOW attainment, and the HI-FLOW group to represent high FLOW attainment. Despite both groups reporting relatively high levels of FLOW, differences in autonomic regulation were found between the groups.

**ANS Regulation and Global FLOW.** Higher levels of reported FLOW for the dancers’ on-stage performance were associated with overall lower values of LFn. A tendency was found, albeit insignificant, with a decrease in the ratio of LF:HF ($p = .052$), as well. Furthermore, analysis of variance showed a difference in these markers during performance when the sample of dancers was split into two groups based on the median split of their total FLOW scores. The HI-FLOW group had a 46% decrease in LFn ($M = -46.35$, $SD = 25.51$) and overall lower values of LFn and LF:HF during performance (LFn: $M = 0.33$, $SD = .15$ and LF:HF: $M = 3.49$, $SD = 2.34$). Conversely, the LO-FLOW group had an approximate 18% decrease in LFn ($M = -17.97$, $SD = 25.70$) from pre-performance to performance and higher LFn and LF:HF (LFn: $M = 0.54$, $SD = .16$ and LF:HF: $M = 7.54$, $SD = 4.05$). This difference between the FLOW groups revealed that lower values of LFn were related to higher state FLOW levels.
during performance. It should be noted, rather than being a marker of pure sympathetic tone, LF has shown to represent modulation of both parasympathetic and sympathetic efferent activity on the function of the baroreflexes (Pagani et al, 1986; Rahman et al, 2011). This decrease in the low frequency power of heart rate variability and LF:HF in relation to higher FLOW reports, was consistent with previous studies that show diminished baroreflex sensitivity under conditions that elicited greater sympathetic modulation, such as exercise or autonomic blockades (Ahmed, Kadish, Parker, & Goldberger, 2011; Brenner, Thomas, & Shephard, 1997). From pre-performance through performance, the dancers who reported greater levels of state FLOW likely experienced an exacerbated cardiovascular stress response during this time period. A potential explanation for such findings could be due to a rise in mean arterial pressure (MAP), causing increased levels of circulating catecholamines, which trigger an influx of sympathetic stimulation, and diminishing baroreflex response (indicated by decreased LFn and LF:HF), ultimately eliciting a greater subjective FLOW experience for the dancer while dancing.

In conjunction with the above findings, a greater increase in the change in heart rate (HR) from pre-performance to performance in the dancers was evidential of greater (or increased) sympathetic tone during this time segment in those reporting high state FLOW. In the HI-FLOW group, the dancers experienced a 48% increase in HR ($M = 48.39, SD = 14.09$), whereas the dancers in the LO-FLOW group only experienced a 23% rise in HR ($M = 23.35, SD = 19.49$) from pre-performance to performance. This, once again, supports that higher global FLOW experience follows greater sympathetic activation and mediation in dancers. During increased exercise intensity, Robinson et al. (1966) found at a heart rate of approximately 150 bpm, vagal modulation was almost
completely withdrawn, and baroreflex sensitivity was almost undetectable due to the bombardment of sympathetic efferent activity. In the current study, the HI-FLOW group had a mean HR of 157 bpm ($M = 157.22, SD = 21.93$ bpm) during performance from approximately 107 bpm during pre-performance ($M = 106.69, SD = 19.91$ bpm), rising above the previously mentioned autonomic threshold of 150 bpm, showing almost complete sympathetic modulation during dance performance. Moreover, the mean HR of the LO-FLOW group increased from 108 bpm ($M = 108.19, SD = 12.31$ bpm) during pre-performance to 134 bpm ($M = 133.87, SD = 27.33$ bpm), a significantly smaller increase in HR during this time period due to greater regulatory influence of parasympathetic tone. Although there were no significant differences found in regards to vagal mediation based on FLOW attainment, it is possible that the LO-FLOW group showed greater vagal mediation from pre-performance to performance, resulting in overall lower heart rates, and a potential hindrance from achieving higher state FLOW. It is unclear, however, if higher sympathetic tone during the performance process is facilitative to reaching a higher global FLOW state, or if higher FLOW allows for the greater sympathetic response.

High-frequency (HF) power of HRV is considered to be a primary marker for vagal modulation in empirical research (Berntson, Cacioppo, Binkley, Uchino, Quigley, & Fieldstone, 1994; Cacioppo, Berntson, Binkley, Quigley, Uchino, & Fieldstone, 1994). In an analysis of variance, the univariate test of between-subjects effects found that anxiety levels based on BAI (Beck Anxiety Inventory) scores had a secondary effect at the different performance time periods for both HI-FLOW and LO-FLOW groups on the autonomic marker of HFn. In general, the dancers’ HFn decreased from baseline (LO: $M = .45, SD = .13$; HI: $M = .49, SD = .17$) through performance (LO: $M = .13$, $SD = .13$).
SD = .06; HI: M = .17, SD = .06), and increased from performance to post-performance (LO: M = .33, SD = .14; HI: M = .39, SD = .21). The BAI is a measure of pathological anxiety and panic disorder. It is possible that this secondary effect of this type of anxiety measure on the withdrawal of this fundamental parasympathetic modulator during performance in both the FLOW groups was a facilitator of the global FLOW experience for this group of dancers. Thomson and Jaque (2012a) disclosed similar results; dancers in their study reported high dispositional global FLOW, despite scoring moderate to severely high on the BAI, indicating fairly elevated levels of clinical anxiety. It should also be noted, that between the HI-FLOW and LO-FLOW groups, the HI-FLOW groups not only displayed higher values for parasympathetic modulation throughout the performance process, but they also had greater sympathetic dominance from pre-performance to performance.

A profound finding in the current study involved the relationship between the bivariate model of autonomic space and the attainment of global FLOW among the sample of dancers. With and without the use of anxiety as the covariate, correlational analyses found a positive relationship between the percent change in CAB (cardiac autonomic balance) from baseline to performance and total FLOW; when there is a greater change that occurs with reciprocation between the autonomic branches, global state FLOW is greater as well. Despite anxiety’s affect associated with HFn, as previously discussed, this change in CAB through these time periods of performance was almost equally related regardless of whether or not anxiety was accounted for. Similar graphs for the bivariate model of autonomic space, designed by Berntson et al., (2008), were created for the dancers in this study to display this greater change, or shift, in cardiac autonomic balance along the CAB continuum in relation to reported FLOW.
state. It is easy to see the transition of CAB down the continuum with the withdrawal of the PNS and increase in SNS activity from baseline through the on-stage performance. This shift towards more sympathetic dominance appears more apparent with the generally high FLOW scores of the dancers in this study. This finding is consistent with the other statistical findings in this study, as well as in accordance with Thomson and Jaque (2011) who found a similar decrease in CAB with reports of high state and dispositional FLOW in multiple types of performing artists, including dancers. An auxiliary point to this finding with CAB was that total FLOW was related to this change whether or not anxiety was controlled for; it is likely that FLOW and anxiety are two psychological states that can occur at the same time (Thomson & Jaque, 2012a; Thomson & Jaque, 2012b); anxiety may possibly be a facilitator to FLOW attainment in dancers.

**ANS Regulation and FLOW subscales.** The nine subscales of FLOW are the characteristics determined to be the most influential for reaching a positive “high” during peak performance (FLOW) within various domains of physical activity, including sports and performing arts (Jackson & Cziksenmihalyi, 1999). In an analysis of variance, differences were found between the HI-FLOW and LO-FLOW groups for the following subscales: CSB (Challenge Skill-Balance), AA (Action Awareness Merging), CG (Clear Goals), UF (Unambiguous Feedback), CTH (Concentration on the Task at Hand), SC (Sense of Control), and AE (Autotelic Experience). These differences between the two groups among the majority of the subscales suggest that slight differences of these elements from dancer to dancer can affect their overall FLOW experience even though, as previously displayed, the dancers, as a whole, achieved a moderate to high level of subjective FLOW state based on their performance.
TT (Time Transformation) and LSC (Loss of Self-Consciousness) were not found to be significantly different between the two groups. These two related subscales exhibit an intense performance based focus that allows a performer to be fully immersed in their performance, so much so, that time and movement pass effortlessly and seamlessly (Csiksenmihalyi, 1990; Jackson & Csiksenmihalyi, 1999). The sample of dancers in the current study rated the lowest on these two subscales (below 4.00) likely because, dependent upon choreography, many of the dancers were on and off the stage, or stopped and started dancing periodically throughout their performance. The necessity to stay with timing and staging of their routine and maintain kinesthetic awareness of their movement could have potentially hindered the dancer’s perception of FLOW based on TT and LSC.

High FLOW attainment in the dancers was supported with partial correlation analyses revealing significant relationships between many of the subscales and markers of autonomic regulation, which displayed dominant sympathetic mediation in the dancers. The dancers felt their ability to establish Clear Goals (CG) was positively related to a 37% increase in heart rate from pre-performance to performance (pre-performance was established as the three-minutes immediately prior to the beginning their dance routine). HR increased from approximately 107 bpm ($M = 107.40$, $SD = 15.08$) to 146 bpm ($M = 146.23$, $SD = 26.67$). It is easy to speculate that the dancers endorsed firm objectives for their performance during this time; setting clear and specific goals can facilitate a more enjoyable execution for the dancer and enhance global FLOW experiences.

In previous FLOW research of performing artists, Challenge-Skill Balance (CSB) and Autotelic Experience (AE) are two of the most important subscales of
FLOW in regards to achieving this ideal psychological state (Cziksenmihalyi, 1990; Hefferon & Ollis, 2006). Among the dancers used in this study, these subscales, along with Activation Awareness Merging (AA) were found to be positively associated with the relative change in CAB from baseline to performance. A decrease in CAB during this time period was also associated with global FLOW; CSB, AE, and AA were likely the main contributors to that relationship. The level of preparedness and the intrinsic motivational drive towards their particular performance may have perpetuated the decrease in autonomic reciprocation down the CAB continuum.

Loss of Self-Consciousness (LSC) was inversely related to a 471% increase in LF:HF ($M = 471.20$, $SD = 460.43$) and positively related to a 73% decrease in RSA ($M = -73.33$, $SD = 19.82$) from baseline through performance. The changes seen with these autonomic markers coincide with previously stated findings of increasing sympathetic tone (and withdrawal of vagal mediation, as seen with decreasing RSA) in the dancers from baseline to performance. It is proposed that with increasing sympathetic tone LSC is negatively impacted in these dancers. During heightened states of sympathetic stimulation, dancers may need to stay aware of their performance environment, such as staging cues and technical skill demands, instead of being fully immersed or lost, in the dance.

Of the nine subscales, Sense of Control (SC) was the subscale that appeared to exhibit the greatest impact on the autonomic regulatory process of the dancers. There was an inverse relationship found between SC and the very low-frequency (VLF) band of heart rate variability (HRV) from pre-performance to performance, as well as with the normalized value of VLF during performance. VLF decreased approximately 19% ($M = -19.28$, $SD = 20.08$). This resonated with an increase in the sense of control (SC)
among the dancers during this time period. Reports of high SC were also associated with an increase in HR of approximately 108% from baseline through performance ($M = 107.90, SD = 38.72$), with 37% of that increase in HR derived from pre-performance to performance ($M = 36.61, SD = 20.77$).

VLF is often associated with the sensitivity of peripheral chemoreceptors, which generally function to detect oxygen level changes in the blood. A low level of oxygen detected in the blood triggers a sympathetically driven cardiorespiratory response (increase in blood pressure and increase in breathing) in an attempt to maintain homeostasis. Previous research has demonstrated an increase in VLF occurred with heightened sympathetic tone and withdrawal of vagal mediation in CHF patients (imbalance of autonomic regulation at rest) and in healthy subjects during moderate to high intensities of exercise (Perini et al., 1990; Ponikowski et al., 1996). The increased VLF in these studies was likely due to the hypoxic and untrained states of the subjects. In the current study, from pre-performance to performance, the dancers had heightened sympathetic tone that was associated with reported high levels of global FLOW and the FLOW subscales; the escalation of HR in relation to SC is a prominent example. However, in contrast to Perini et al. (1990) and Ponikowski et al. (1996), the dancers showed a decrease in VLF, despite prominent sympathetic mediation during this time period. It could therefore be postulated, that the highly trained dancers in the current study were able to better control their breathing and maintain higher blood oxygen levels throughout the performance process (pre-performance through performance), physiologically displaying decreased chemoreceptor sensitivity and VLF oscillations of HRV. If the dancers were able to better regulate their breathing, the
dancers may have been able maintain a better perception of control (SC) over their performance.

**Limitations**

The present investigation analyzed the physiology of global FLOW experience and the nine associated subscales in dancers. This study offers an analysis of how dancers physiologically regulate during times of peak performance. Limitations in the study include inherent subjective limitations when using self-report instruments, such as the FSS-2 and BAI-II. Dance may be regarded as a positive domain of artistic expression, thus creating an environment for a dancer to achieve high FLOW experiences (Hefferon & Ollis, 2006; Thomson & Jaque, 2012a). The modest sample size of the study was also a limiting factor. The dancers were split into two groups representing HI-FLOW and LO-FLOW. These groups were determined based on a median split of high global FLOW mean scores. With a larger sample size, there could potentially be greater variation in scores, lending to stronger significance in the results. A better demonstration of the autonomic regulatory processes of dancers could be displayed with a larger number of study participants along the bivariate continuum of autonomic space (CAB and CAR).

**Conclusion**

Dancers are the athletes of their art; they strive for peak performance. They are highly likely to experience the psychological FLOW state when participating in dance because they find the experience to be extremely satisfying, achievable yet challenging, and absorbing (Jackson & Csikszentmihalyi, 1999). The current study strove to quantify this experience in dancers by measuring the FLOW experience with the relationships and changes of autonomic regulation during the performance process.
Dancers reported relatively high states of FLOW for their on-stage performance; higher FLOW experiences were associated with dominant sympathetic modulation from resting baseline measures through the performance, with the greatest measures of sympathetic increase occurring from pre-performance to performance. Surprisingly, of the nine FLOW state subscales, Sense of Control (SC) was most influential, and potentially facilitating, to dancers’ FLOW from base to performance. Dancers felt a greater sense of control over their performance when highly sympathetically activated.

This is one of the first known studies to analyze the psychophysiological response of dancers during the on-stage performance process and assess regulation along an autonomic regulatory continuum. The concept of the bivariate continuum of autonomic regulation (autonomic space) slightly differs between psychological stressors and physiological stressors (Berntson et al., 1994; Cacioppo et al., 1994). The difference between autonomic regulation based on the psychological and physiological influences in dancers would be an avenue of investigation for future research. The change in CAB seen from baseline to performance in relation to global FLOW attainment and the specific subscales CSB, AA, and AE, were the only relative autonomic shifts along this continuum for the current study; however, there were insignificant, but interesting, transitions of ANS balance and reactivity apparent when the data were plotted. In reference to the graphs of autonomic space for each time period of the performance process, some dancers fell within the coinhibition of PNS and SNS modulation during post-performance; other dancers displayed uncoupled activation (no change in one autonomic branch, while the other increased or decreased). With a larger sample size, a stronger display of directional regulation may be seen. In general, regulation along the CAB continuum is considered to be cardioprotective (Berntson et
al., 2008); under this assumption, how the dancer regulates under these conditions could be indicative of underlying psychological and/or physiological disorders. In this investigation of subjective FLOW attainment, the use of fundamental quantitative measures of autonomic regulation and the more recently developed bivariate model, the current study aimed to bridge the gap in research and extend the connection between psychological and physiological regulation to help dancers achieve heightened FLOW experiences.
References


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