Biomolecular Effects of Dance and Dance/Movement Therapy: A Review

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Accepted: 21 May 2022 / Published online: 23 June 2022
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Abstract
The positive health impacts of dance and dance/movement therapy can be seen all the way down to the molecular level. This narrative-style review illustrates this connection by presenting a collection of clinical and preclinical studies that evaluate the effects of dance activities on hormones and other small-molecule metabolites within the human body. The results of these studies show that dance activities can increase levels of nitric oxide, serotonin, estrogen hormones, and HDL cholesterol, while they can decrease levels of dopamine, serum glucose, serum triglycerides, and LDL cholesterol. Levels of cortisol can either be increased or decreased, depending on the type of dance. Many of these results parallel the biomolecular effects of traditional (non-dance) exercise activities, although some contrasting results can also be seen. The concentrations of these molecules and their distributions throughout the body impact health and a wide variety of disease states. This connection to the molecular level provides a perspective for understanding how it is that dance activities are able to affect larger-scale physiological and psychological responses and lead to the positive health outcomes that are observed in many situations.

Keywords Dance · Dance/movement therapy · Biochemistry · Health · Small-Molecules · Metabolites

Abbreviations
ATP  Adenosine triphosphate
ELISA  Enzyme-linked immunosorbent assay
HDL  High-density lipoprotein
LDL  Low-density lipoprotein
MAPK/ERK  Mitogen-activated protein kinase / extracellular signal-regulated kinases
VO2  Maximum volume capacity of the lungs

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Overview

The goal of this review is to illustrate examples of how dance activities can modulate the levels of various health-related hormones and small-molecule metabolites within the human body, to put these results in an approachable biochemical context, and to compare and contrast them to related effects from non-dance exercise activities. Each section of this review focuses on a particular molecule of interest. Table 1 lists these molecules, indicates some of their key health and disease connections, and overviews the key dance studies that are included in this review. Along with describing these studies, each section also includes an introduction to the molecule’s biochemistry and health relevance as well as important experimental methods for measuring the molecule’s levels. Each sections puts these results in context by comparing them to non-dance exercise studies about the same molecule, by discussing the results, and by articulating key challenges of using these molecules as outcome metrics. A brief conclusion at the end of the article then ties together some common themes seen across various molecules of interest.

The methods of the included studies have some recurring themes, but also some different approaches. Many of the studies are multi-month programs in which a test group participates regularly in a dance activity, such as dance/movement therapy, square dance, Zumba, aerobic dance, or dance exergaming. The test groups often focus on a particular at-risk population, such as elderly women, persons with dementia or mental health conditions, or those with sedentary lifestyles. Control groups are often either non-exercise groups or groups that do non-dance forms of exercise. Other studies are set up as single-session experiments that compare a session of African dance or Argentine tango for example to control conditions. Study sizes are often medium to small, so appropriate statistical analysis of result is critical. Other studies look at large cohorts of people and search for correlations between reported lifestyle choices and disease outcomes. Concentrations of the molecules of interest are generally measured from blood or saliva samples, which are typically collected both before and after the intervention. A variety of measurement techniques are used, which include colorimetric assays, antibody-based detection assays, and liquid chromatography. Most of these studies also collected information about physiological, psychological, or other larger-scale health outcomes, so that these measurements can be correlated to the molecular-level results.

Molecules of Interest

Nitric Oxide

Nitric oxide performs critical signaling functions within the human body. This molecule has been thoroughly studied as a regulator of the cardiovascular system.
| Molecule studied | Disease & health relevance | Study | Participants | Duration | Dance activity & result |
|------------------|-----------------------------|-------|--------------|----------|-------------------------|
| Nitric Oxide     | Cardiovascular health       | Filar Mierzwa (2017) | 39 (elderly women) | 12 weeks | Dance/movement therapy 19% Increase, $p = 0.03$ |
|                  | Hypertension                |       |              |          |                         |
| Serotonin        | Depression                  | Jeong et al. (2005)  | 40 (girls with depression) | 12 weeks | Dance/movement therapy 10% Increase, $p < 0.005$ vs Control Decreased depression symptoms |
| Dopamine         | Parkinson’s disease         | Jeong et al. (2005)  | As above     | As above | Dance/movement therapy 7% decrease, $p < 0.001$ vs Control |
|                  | Huntington’s disease         |       |              |          |                         |
|                  | depression                  |       |              |          |                         |
| Estradiol        | Reproductive health         | Xiaoyan and Jianhua (2017) | 80 (postmenopausal women) | 6 months | Square dance 48% Increase, $p < 0.0001$ Increased Bone Density |
|                  | Premenstrual syndrome       |       |              |          |                         |
|                  | Osteoporosis                |       |              |          |                         |
| Cortisol         | Stress                      | West et al. (2004)   | 69 (college students) | Single Session | African dance 67% Increase, $p < 0.0001$ Decreased Perceived Stress |
|                  | Sleep problems              |       |              |          |                         |
|                  | Obesity                     | Murcia et al. (2009) | 22 (dancers) | Single Sessions | Argentine tango 20% Decrease, $p < 0.001$ vs Control |
|                  |                             | Vrinceanu et al. (2019) | 40 (healthy adults) | 3 Months | Dance/movement therapy 30% decrease, $p = 0.01$ |
|                  |                             | Ho et al. (2020)     | 240 (Elderly Persons with Dementia) | 3 Months | Dance/movement therapy Decreased Diurnal Slope, $p < 0.01$ vs Control Decreased Loneliness, Depression, and Negative Mood Scores |
| Glucose & Insulin| Obesity; Type 2 diabetes; cardiovascular disease; organ damage | Passos et al. (2021) | 23 (Women with or without Diabetes) | 4 Months | Recreational aerobic dance 17% Decrease for Glucose, $p < 0.05$ |
| Molecule studied | Disease & health relevance | Study | Participants | Duration | Dance activity & result |
|------------------|-----------------------------|-------|--------------|----------|-------------------------|
| Triglycerides    | Stroke; cardiovascular disease; cognitive functions | Staiano et al. (2017) | 41 (Overweight Teenage Girls) | 12 Weeks | Dance Exergaming Less Increase than Control Group, n.s Decreased Body Fat |
|                  |                             | Araneta and Tanori (2015) | 13 (Women) | 12 Weeks | Zumba Dance 11% Decrease, $p < 0.05$ Decreased Blood Pressure |
|                  |                             | Kin et al. (2001) | 45 (Female Students) | 8 Weeks | Aerobic dance 22% Decrease, $p < 0.01$ |
|                  |                             | Han et al. (2001) | 43 (Elderly Men) | 12 Weeks | Therapeutic recreational dance 28% Decrease in Unhealthy Group, $p < 0.01$ Increased Muscular Endurance |
| Cholesterol      | Cardiovascular disease; stroke | Lin (2021) | 95,247 | Lifestyle Survey | Dance revolution players 4% Elevated HDL levels Ballroom dancers 3% Elevated HDL levels |
|                  |                             | Rodrigues-Krause et al. (2018) | 37 (Older Women) | 8 Weeks | Dancing 10% HDL increase, $p < 0.001$ |
|                  |                             | Kin et al. (2001) | As above | As above | Aerobic dance 17% Total Cholesterol Decrease, $p < 0.01$ |
|                  |                             | Han et al. (2001) | As above | As above | Therapeutic recreational dance 16% LDL decrease in unhealthy group, $p < 0.01$ 15% HDL increase in unhealthy group, $p < 0.01$ |
|                  |                             | Passos et al. (2021) | As above | As above | Recreational Aerobic Dance 15% cholesterol decrease in diabetic group, $p < 0.05$ |
Overall, it signals the cardiovascular system to relax, for example by relaxing the smooth muscle tissue that surrounds blood vessels, lowering blood pressure, reducing heart rate, inducing blood vessel growth and repair, and reducing clogging of arteries. These physiological effects reduce the risk of heart disease and high blood pressure. Nitric oxide is also generated in the brain, where it functions to enhance signaling between neurons, both by stimulating neurotransmitter release and by serving as a messenger molecule for non-synaptic neural communication (Akyol et al., 2004; Vizi, 2000). Nitric oxide also affects various other biochemical signaling pathways, such as the MAP/ERK pathway, which influences survival and proliferation of multipotent adult stem cells (Bonafe et al., 2015). Several pharmaceutical drugs that are either already approved in the United States or are under development function by manipulating the same biochemical pathways that are modulated by nitric oxide signaling.

Nitric oxide, which contains just two atoms (one nitrogen and one oxygen), is much smaller than typical organic hormone molecules and orders of magnitude smaller than peptide and protein hormones. Furthermore, nitric oxide’s structure contains an unpaired electron, which makes it highly reactive. After being synthesized by nitric oxide synthase enzymes in areas of the body, the nitric oxide molecules activate local signaling pathways and then rapidly decompose, which stops the signaling.

Nitric oxide levels can be measured by colorimetric assays. Since nitric oxide rapidly decomposes into nitrite and nitrate ions, it is the concentration of these ions that is measured. In typical nitrite/nitrate assays, which are commercially available as kits (Cayman, 2016; Sigma, 2018), nitrate reductase enzymes reduce the nitrate ions into nitrite ions, and then the oxidizing power of the nitrite ions induce a chemical reaction that generates a highly colored product. Thus, the amount of color produced is proportional to the amount of nitric oxide that was originally in the sample.

A study by Filar-Mierzwa et al. (2017), which compared the effects of dance/movement therapy versus general rehabilitation exercises on elderly women, reported that dance/movement therapy can increased nitric oxide levels. The 41 participants in this study had an average age of 67 years old, and all had sedentary lifestyles. Participants were divided into a dance/movement therapy group (n = 19) and a general exercise group (n = 20). The general rehabilitation exercise consisted of conventional physical therapy, strengthening exercises, and balance training. The two programs lasted for 12 weeks. Blood samples were collected before and after the 12-week intervention, and nitric oxide levels were analyzed from the plasma using a nitrate/nitrite colorimetric assay. The authors specifically noted that the groups of measured values do not form normally distributed Gaussian patterns, so statistical analysis needed to be performed with non-parametric tests. The nitric oxide levels in the dance/movement therapy group showed a statistically significant increase from before to after the intervention (+ 19% increase of mean, + 7% increase of median, p = 0.03). In contrast, the data from the general rehabilitation exercise group did not show any significant change.

Nitric oxide levels can also be influenced by traditional (non-dance) exercise. A study by Hasegawa et al. (2018), for example, showed that either aerobic training or high-intensity interval training programs can increase nitric oxide levels and
decrease arterial stiffness. In this study, sedentary male volunteers ($n = 21$) in their early 20 s were divided into three groups. The aerobic training group cycled three times a week for eight weeks, the interval training group performed short bursts of high intensity exercise four days a week for six weeks, and those in the control group maintained their normal low activity routines. Nitric oxide levels were measured from blood samples before and after the interventions. While the nitric oxide levels in the control group decreased by approximately 20%, the levels in the two exercise groups increased by approximately 35% for the aerobic group and 20% for the interval group. Both changes are statistically significant compared to the control group ($p < 0.05$). Statistically significant decreases in arterial stiffness were also observed for both exercise groups compared to the control group, which illustrates how changes at the molecular level can correlate with changes at the physiological level.

Nitric oxide levels can even be affected by a single session of exercise. A study by Boeno et al. (2019), for example, compared the effects of single session high intensity versus moderate intensity strength training exercise on blood plasma nitric oxide levels. The participants of this study were 11 middle-aged sedentary men. All the subjects participated in three experimental conditions: high intensity resistance exercise, moderate intensity resistance exercise, and resting control, on three different mornings. Blood samples were collected before, immediately after, and 1 h after the experimental condition, and nitric oxide levels were analyzed using a nitrate/nitrite colorimetric assay. The results show that nitric oxide levels had increased by 85% after the moderate intensity exercise intervention ($p = 0.007$). In contrast, the high intensity exercise condition and the resting control condition did not produce any significant changes.

Together, these studies show that dance activities can provide some of the same health benefits as traditional exercise. The results suggest that moderate intensity aerobic exercise is an effective way to increase nitric oxide levels in the blood, and that dance can also have this same effect. Filar-Mierzwa et al., (2017) specifically noted that participants in their dance/movement therapy group were more motivated and satisfied with the dance-based exercise routine compared to those in the traditional exercise group, which suggests that dance/movement therapy can be a good option for people who do not enjoy conventional exercise, but still want to benefit from the positive health effects of being physically active.

**Serotonin**

Serotonin is a signal molecule that affects a wide variety of physiological functions. Within the nervous system, serotonin functions as a neurotransmitter and plays critical roles in promoting positive mood, healthy sleep patterns, cognitive brain functions, neuroplasticity, learning, memory, and body temperature regulation, as well as quenching hunger and decreasing pain sensitivity (Jenkins et al., 2016; Kraus et al., 2017; Voigt & Fink, 2015). Low levels of serotonin in the central nervous system have been shown to contribute to depression symptoms (Jenkins et al., 2016), and some common anti-depressant medications act by enhancing serotonin pathways in
the brain. The majority of serotonin in the body, however, is found outside of the nervous system, especially in the gut. In the body, serotonin influences many functions such as the functioning of the intestinal track and energy metabolism (Berger et al., 2009; Spohn & Mawe, 2017).

Serotonin concentrations from blood samples can be measured with liquid chromatography instruments. Electrochemical detectors are typically used because they are sensitive enough to measure very low concentrations, especially for amine-containing molecules such as serotonin (ThermoFisher, 2020; Horvai et al., 1987). Electrochemical detectors use an electrical current to initiate a Redox reaction with the compound of interest. For any compound, the amount of electrical current produced is proportional to its concentration, so the amounts of a particular molecule can be easily compared across multiple samples.

A study conducted by Jeong et al., (2005), which examined the effects of dance/movement therapy on adolescents diagnosed with mild depression, showed that dance can increase serotonin levels. In this study, 40 middle school girls who showed symptoms of depression were randomized into dance movement (n = 20) and control (n = 20) groups. The dance intervention consisted of 45-min dance sessions that were held three times a week for 12 weeks. Blood samples were collected before and after the 12-week intervention. Serotonin levels were measured by liquid chromatography analysis with electrochemical detection. The results of this study showed that by the end of the 12 weeks, the average plasma serotonin level in the dance group had increased by approximately 10%, whereas in the control group, it had slightly decreased. Due to the large standard deviations among individuals, neither of these changes is statistically significant on its own; however, the difference between the changes in the two groups is statistically significant (p < 0.005). The subjects in the dance group also showed a statistically significant decrease in psychological symptoms based on self-report surveys, which suggests a connection between the molecular-level effects and larger-scale effects.

In contrast, exercise can cause a decrease in serum serotonin levels. A study by Pietta-Dias et al., (2019), for example, compared the effects of endurance, strength, and combined training on plasma serotonin levels in healthy elderly women, and found significant decreases in blood serotonin levels. This 12-week study was composed of four cohorts: a strength training group (n = 12), an endurance training group (n = 12), a combined training group (n = 12), and a control group (n = 12). Participants in the strength training group did leg presses, knee extensions, and abdominal exercises, participants in the endurance training group utilized the treadmill, and participants in the combined training group did a combination of strength and endurance exercises. The control group was instructed to not participate in any physical activity throughout the duration of the study. Blood samples were collected on the day prior to beginning intervention and the day after intervention was completed. Plasma serotonin levels were quantified using high performance liquid chromatography. The data show a significant reduction of peripheral serotonin for all exercise groups (approximately 50% decrease for endurance training, p = 0.001; approximately 70% decrease for strength training, p = 0.012; and approximately 60% decrease for combined training, p = 0.019) compared to no significant change for the control group.
It is challenging, however, to draw direct correlations between blood serotonin levels and the effects that serotonin causes in the brain. Serotonin cannot cross the blood–brain barrier, and it is therefore believed that serotonin exists as two distinct pools within the body: one in the central nervous system, and one in the peripheral body (Spohn & Mawe, 2017). Both pools are synthesized from tryptophan, and the amount of tryptophan that is transported into the brain has a major influence on the amount of serotonin that is synthesized in the brain. Increasing or decreasing tryptophan levels in the blood, for example by controlling diet, increases or decreases serotonin levels in both the brain and the peripheral body (Spohn & Mawe, 2017). Tryptophan availability in the blood and transportation into the brain is also affected by complex interactions with fatty acids, albumin, insulin, and glucose (Fernstrom & Fernstrom, 2006; Strüder & Weicker, 2001). Thus, while serum serotonin levels can be easily measured, it can be challenging to assess the positive impact on mood that can result from increasing serotonin in the brain by simply measuring its concentration in the blood. For example, although exercise can decrease serum serotonin levels, for example, it is known to have the opposite effect of increasing serotonin in the brain (Fernstrom & Fernstrom, 2006).

Dopamine

Like serotonin, dopamine is a neurotransmitter that influences many different pathways. Within the brain, dopamine is a key signal molecule for movement control, learning, motivation, reward and reinforcement, and hormone regulation (Klein et al., 2019). Destruction of neurons that produce dopamine and that are involved in dopamine-based signaling pathways causes the symptoms of Parkinson’s disease and Huntington’s disease, whereas alterations to dopamine receptors and dopamine-based signaling pathways are believed to contribute to the symptoms of schizophrenia, attention deficit hyperactivity disorder, addiction, and depression (Grace, 2016; Klein et al., 2019; Tarazi, 2001). Dopamine also plays a role in signaling in the peripheral body. Dopamine’s molecular structure is similar to that of serotonin, and dopamine levels in blood can be measured similarly to how serotonin levels are measured.

In the study described above by Jeong et al. (2005), which examines the effects of dance/movement therapy on adolescents diagnosed with mild depression, the results also showed changes in plasma dopamine levels. Dopamine levels in the dance group had decreased by approximately 7%, whereas they had increased by approximately 3% in the control group ($p < 0.001$ between groups).

As with serotonin, understanding the relationship between plasma concentrations of dopamine and disease-relevant symptoms is challenging. As with serotonin, dopamine cannot cross the blood–brain barrier. It is made in both the body and brain from tyrosine, via the L-dopa intermediate. Thus, the relationship between the concentration of dopamine in the blood and in the brain is complex. Furthermore, since the major diseases that are associated with dopamine result from destruction of neurons and alteration of receptors, it is not fully clear how altering dopamine levels in the brain will impact the specific symptoms of these diseases.
Estrogen

The estrogens are an important family of hormones in the human body. Estrogens influence ovulation, the preparation of the endometrium for pregnancy, and other key processes within the female reproductive system (Findlay et al., 2010). Estradiol, which is the primary female gonadal hormone, is the most common type of estrogen. Males also produce estradiol, and it is necessary for their reproductive health (Russell & Grossmann, 2019; Schulster et al., 2016). For example, men need estradiol for the proper completion of spermatogenesis and the proper fulfillment of pubertal development (Schulster et al., 2016). Estradiol is particularly important for skeletal health given that it promotes the differentiation and inhibits the apoptosis of osteoblasts, which are the cells that are responsible for the formation of new bone (Russell & Grossmann, 2019; Yang et al., 2013). Estradiol also plays a role in the nervous system. Evidence suggests that this hormone induces dendrite and synapse proliferation in neurons by promoting phosphorylation of the Ras/MAPK/ERK signaling pathway. This function makes estradiol an important molecule for cognition and memory preservation. Other studies have found that estradiol induces nitric oxide production by promoting phosphorylation, and therefore activation, of nitric oxide synthase, which is the enzyme responsible for nitric oxide production (Fredette et al., 2018).

Estradiol levels can be measured by radioimmunoassays. In this technique, a small but precisely measured amount of synthetic estradiol that is bound to a radioactive isotope, such as $^{125}$Iodine, is mixed with the sample to be analyzed. The amount of natural estradiol in the sample is determined by assessing what percent of the total estradiol in the sample contains the isotope. This determination is made by allowing the labeled and non-labeled molecules to compete to bind an antibody that specifically binds to estradiol (with or without the radiolabel). Unbound estradiol is washed away, and the amount of radioactivity is measured and compared to a standard curve. Since antibody-antigen interactions are very specific, antibody-based analytical methods typically have very high specificity and can distinguish one molecule from other molecules that have similar structures (Grange et al., 2014).

A study conducted by Xiaoyan and Jianhua (2017) showed that a six-month square dance program in combination with calcium supplementation can increase estradiol levels and bone density in postmenopausal women better than calcium supplements on their own. 80 participants were randomized into experimental and control groups. Both groups received 600 mg daily doses of calcium for the duration of the study. The experimental group also participated in 60–90-min square dance exercises 3–5 times a week for a period of six months. The exercise intensity caused participants to typically achieve 60–70% maximum heart rates. Blood samples were obtained at baseline and after three and six months of intervention. The levels of serum estradiol were measured using a radioimmunoassay. Prior to the beginning of the study, there was no significant difference in estradiol levels or bone density between experimental and control groups. By the end of the six-month study, however, the average serum estradiol levels in the dance group had increased by 48% ($p < 0.0001$). Additionally, the serum levels of progesterone, which is another female sex hormone and biochemical precursor to estradiol, had increased by 16%
Bone density in the tibia and heel had increased by 22% and 29%, respectively \((p < 0.01)\). In contrast, the control group did not show any meaningful changes in serum estradiol or progesterone and showed slight decreases in bone density that do not meet the criteria for statistical significance. These results show that regular dance-style exercise can not only increase serum hormone levels in postmenopausal women, but can also enhance the impact of calcium supplements on bone development. Thus, dance can provide a straightforward preventative treatment for reducing osteoporosis risk.

Non-dance exercise has also been reported to influence estradiol and progesterone levels. A study by El-Lithy et al. (2015) evaluated the effect of aerobic exercise on the hormone levels and premenstrual syndrome symptoms in young women. 30 participants, aged 16–20, who did not engage in regular exercise were split into exercise and control groups. Both groups received calcium and vitamin B6 supplements, and the exercise group also participated in a 30-min treadmill exercise program three times a week for three months. Blood samples were collected from participants on day 20 of their menstrual cycle before and after the three-month intervention. Over the course of the treatment, estradiol and progesterone levels in the exercise group decreased by 24% \((p = 0.01)\) and 41% \((p = 0.01)\), respectively, while those in the control group increased slightly by statistically insignificant amounts. The exercise group also showed significant decreases in all six premenstrual syndrome symptom scores, as assessed by a participant questionnaire, \((p < 0.01)\). Furthermore, blood hemoglobin levels, which help prevent symptoms of anemia, had increased by 21% \((p < 0.05)\) in the exercise group.

Increases or decreases in estradiol and progesterone levels can be desirable in different situations. For older women, the natural decrease in estrogen levels can contribute to osteoporosis. Therefore, activities and lifestyle choices that increase estrogen for these populations can increase health. Dance based exercise can have this effect. For younger women, exercise can lessen the surges in estrogen and progesterone levels that occur during normal menstruation cycles and reduce the symptoms of premenstrual syndrome and anemia. Although dance and other forms of exercise can produce different effects on estrogen hormone levels for different people at different moments of life, these activities generally promote health and happiness.

**Cortisol**

Cortisol is a hormone that has been thoroughly studied for its role in the body’s response to stress (Adam et al., 2017; Fiksdal et al., 2019; Lee et al., 2015). This molecule is secreted by the adrenal cortex. Its concentration in the body naturally varies throughout the course of a day, rising to a maximum in the morning soon after a person wakes up, and then declining throughout the day until the late evening. High cortisol levels promote alertness and energy metabolism and prime the body for activity, so the daily cortisol cycle helps people to wake up in the morning, be active throughout the day, and then fall asleep at night (Adam et al., 2017). Lower levels of cortisol at night promote healthy function of the immune system. Chronic psychological stress and physical pain can affect the normal cycle of
cortisol concentration by preventing it from sufficiently lowering at the end of the day. This disruption can cause numerous health issues, including sleep problems, obesity, defects in the immune system, and even cancer (Adam et al., 2017). Preliminary findings suggest that cortisol may also have a role in depression and anxiety (Adam et al., 2017; Fiksdal et al., 2019).

Cortisol levels can be measured from saliva samples by enzyme-linked immunosorbent assays (ELISAs) (Grange et al., 2014). Like radioimmunoassays, ELISAs utilize antibodies to selectively bind to the antigen to be measured. In a typical setup, the antibody is attached to the surfaces of a plastic well plate, the antigen to be measured is bound by the antibody, and non-bound material is washed away. The amount of antigen that is attached to the surface of the well plate is then measured by having a second antibody bind to it. This second antibody is connected to an enzyme that can produce a colored, fluorescent, or luminescent signal that can be measured and compared to a standard curve.

A study by West et al. (2004) showed that single sessions of African dance or Hatha yoga can each reduce stress while having opposite effects on cortisol levels. 69 college students were split into three groups: dance, yoga, and a control group. The dance and yoga groups completed a 90-min session of the activity while the control group attended a biology class in the late afternoon. Saliva samples were collected, and perceived stress questionnaires were administered before and after the activity. Over the course of the activity, participant scores on the perceived stress questionnaire decreased by 18% and 15% in the yoga and dance groups ($p < 0.001$ for each), while the scores in the control group did not show a substantial change. Salivary cortisol levels in the yoga group decreased by 22% ($p < 0.05$), whereas they showed no change in the control group. In contrast, cortisol levels in the dance group increased by 67% ($p < 0.0001$). These contrasting results are consistent with cortisol levels responding to recent physical activity levels. Hatha yoga is a gentle and calm style of yoga that reduces cortisol levels and decreases stress. African dance, on the other hand, is a physically active style of dance. This dance decreases stress, but it produces a short-term increase in cortisol levels due to the high intensity of the activity. Short-term increases in cortisol in response to physical activity are not a health concern, but, rather, it is when the body’s baseline level of cortisol remains elevated that chronic stress issues can manifest.

A study by Murcia et al. (2009) showed that the inclusion of music and a dance partner can affect how much cortisol levels decrease from a single session of dancing Argentine tango. The participants were 11 male and 11 female dancers who had at least one year of previous tango experience. Over the course of four evening sessions, each participant completed four different experimental conditions: dancing with music and a partner, dancing with a partner but no music, dancing with music but no partner, and moving alone with neither music nor a partner. Each session was at the same time of the evening and lasted 20 min. Saliva samples were collected before and after each experimental condition. Although baseline cortisol levels before these sessions varied quite a bit among individuals and from day to day, significant differences were observed when comparing the amount of cortisol decrease within individuals that was produced by the different 20-min conditions. Dancing with a partner and with music resulted in a cortisol decrease of approximately
20%. Moving alone, either with or without music, resulted in a smaller decrease of approximately 15% (each $p < 0.001$ vs dancing with partner and music). Moving with a partner, but without music resulted in the smallest decrease of approximately 6% ($p < 0.001$ versus solo conditions). Unfortunately, there was not a negative-control condition to compare these decreases to the natural decrease of cortisol throughout the evening in the absence of the 20 min of mindful movement. Nevertheless, partner dancing with the normal accompanying music can produce a more substantial cortisol decrease compared to other related activities that include similarly mild physical exertion.

A study by Vrinceanu et al., (2019) showed that a three-month program in dance/movement therapy can decrease morning cortisol levels in healthy elderly adults. 40 healthy adults were randomized into dance, aerobic exercise, and control groups. Intervention for the dance and aerobic exercise group consisted of 60-min sessions held three times a week for a period of three months. The dance/movement therapy intervention was led by a licensed dance movement therapist. The training for the aerobic exercise group consisted of stationary bicycling. Cortisol levels were measured before and after the three months of intervention. Levels were measured from saliva samples that were collected at awakening, 30 min after awakening, and 1 h after awakening, with three days of replicates. The samples were analyzed using a chemiluminescence immunoassay.

The results of this study show that the dance intervention did have a significant effect on cortisol levels, but that cortisol levels also vary quite a bit from person to person. For the baseline data before intervention, the data from the 30 min after wake up time show that the participants assigned to be in the dance group had significantly higher morning peak cortisol levels than those who had been assigned to be in the aerobic exercise group (16.35 versus 10.80 nMol/L, $p < 0.05$). The standard deviation of these values (7.89 and 3.52) shows that there is a substantial amount of variation among the individuals. Because of this variance, the authors made some adjustment to the raw data based on body-mass-index, sex, and baseline cortisol levels, to normalize the values, and then focused on changes in cortisol levels from before to after the intervention. Based on this analysis, the dance group’s morning cortisol levels had decreased by approximately 30% by the end of the program ($p=0.01$). The exercise group’s levels had decreased by approximately 15%, but due to the large variance within these datasets, this change did not meet the criteria for statistical significance ($p > 0.05$). In contrast, the control group’s cortisol levels had not changed.

Ho et al. (2020) conducted a study to compare the effects of three months of dance/movement therapy or physical exercise on cortisol levels in elderly patients with dementia. Two hundred and four participants who had been diagnosed with dementia or mild neurocognitive disease were randomized into dance movement, exercise, and no-exercise control groups. Subjects in the dance movement and exercise groups engaged in their respective interventions twice a week for 1-h sessions over a span of three months. The dance movement intervention was led by a licensed dance movement therapist. The exercise intervention consisted of stretching and joint movements. Cortisol levels were measured one week before the intervention, after the three months of intervention, and then again three and nine months after
the end of the intervention. For the measurements, saliva samples were collected at five time points throughout the day.

Although no significant differences between the average cortisol levels in the different groups were observed, the authors did observe some differences in the diurnal cortisol slope, which is the rate of cortisol decrease per hour over the course of the day. Interpreting these measurements, however, is a bit challenging. Before the intervention, the control group began with a slope that is notably more negative than those of the exercise and dance groups (0.27 and 0.26 nmol/h more negative, \( p = 0.03 \) and 0.06 respectively), and the standard deviations within each group of measurements are as large as the numbers themselves. The authors focused on how the slope within each group changed over the intervention time. After the three months of intervention, the diurnal cortisol slopes of the participants in the dance group had become more negative by 0.05 nmol/h, which is significantly different from the change observed in the control group, whose slopes had become more positive by 0.06 nmol/h (\( p < 0.01 \) comparing the two changes). The slopes from the exercise group had become more negative by 0.02 nmol/h, which is also statistically significant compared to the control group (\( p = 0.03 \) comparing the two changes). During the nine months following the intervention, the dance group’s slopes steadily decreased an additional 0.16 nmol/h, whereas the exercise group’s slope only decreased an additional 0.09 nmol/h, and the control group’s slope steadily increased an additional 0.15 nmol/h. Participants in the dance group also showed significant decreases in loneliness (\( p < 0.01 \)), depression (\( p < 0.01 \)), and negative mood (\( p = 0.02 \)) compared to the participants in the control group. These results suggest that this type of dance program can have a prolonged positive impact both at the molecular and emotional levels.

**Glucose and Insulin**

The sugar glucose is a major energy source for the body, but increased blood sugar levels can lead to a variety of health risks. Glucose enters the blood after food consumption or when it is released from stored glycogen in the liver. From the blood, it is taken into cells, where it is metabolized to produce ATP. It can cross the blood–brain barrier, where it serves as a major energy source for the cells of the brain (Mergenthaler et al., 2013). Blood sugar levels rise throughout the day, spiking in response to food consumption, and then return to a regulated level during the night. When blood glucose levels remain elevated, however, it can lead to gradual damage to the eyes, kidneys, heart, and vascular system (Gerstein, 1997), as well as acute life-threatening strokes and diabetic ketoacidosis. According to the American Centers for Disease Control and Prevention, people with morning glucose levels of greater than 125 mg / dL are considered diabetic, which represents a significant risk factor, and those with 100–125 mg / dL are considered pre-diabetic, which is still a risk factor (Centers for Disease Control and Prevention, 2021). Type 1 diabetes is caused by an autoimmune disease, whereas type 2 diabetes is not. One risk factor for type 2 diabetes is when the body becomes resistant to insulin (National Institute of Diabetes and Digestive and Kidney Issues, 2018).
Insulin is a hormone that lowers blood sugar levels. Its production is stimulated by high levels of blood sugar, and it then stimulates cells to take glucose from the blood into the cell. It also, indirectly, prevents the liver from releasing extra glucose into the blood. If high blood sugar becomes the norm, however, typically due to poor diet choices, lack of physical activity, and being overweight, then insulin production is constantly being stimulated, and the body gradually decreases its normal response to that insulin and loses its ability to control blood glucose levels. Elevated levels of insulin are risk factors for obesity, type 2 diabetes, and cardiovascular disease (Kolb et al., 2020).

A study by Passos et al. (2021) showed that a four-month program of recreational aerobic dance can decrease blood glucose levels in diabetic women. 11 women with type 2 diabetes and twelve healthy women aged 50–75 completed the dance program, which included two 60-min sessions per week. The dance classes, which were taught by a professional instructor, included Zumba and Brazilian folk dances, and they enabled participants to achieve approximately 55–60% of their heart rate reserve. Blood samples were collected before and after the program, after overnight fasts. Plasma glucose levels were measured by a commercially available colorimetric assay. Before the program, resting blood glucose levels in the diabetic group were 49% higher than those in the control group (p < 0.05). By the end of the program, however, the resting glucose levels in the diabetic group had decreased by 17% (p < 0.05). This change brought them halfway back to the levels seen in the healthy control group. No change was seen in the glucose levels of the healthy control group. These results show that the impact of dance programs can be greater for those people whose baseline health levels are farther from optimal and in the most need of improvement.

A study by Staiano et al., (2017) showed that dance exergaming can have a positive impact on cardiovascular risk factors for overweight and obese adolescent girls; however, the direct effect on serum glucose and insulin levels were challenging to interpret due to variation among individuals. Dance exergaming consists of dancing as a part of a video game, and thus, it can be an appealing activity for some teenagers. 41 obese and overweight female adolescent participants were randomized into an exergaming group (n = 22) and a control group (n = 19). The participants of the exergaming group took part in three 1-h dance exergaming sessions per week for the 12 weeks of the study. Only 11 of the 22 individuals in the exergaming group, however, successfully completed the intervention by attending at least 75% of the sessions and achieving at least 2600 steps per session. Blood samples were collected, following 10-h fasting, before and after the 12-week program. In the exergaming group, serum glucose levels increased by an average of 1% over the course of the study, whereas in the control group, they increased by an average of 13%. Due to high variation among individuals, however, this difference did not meet the criteria for statistical significance (p > 0.2). For the individuals who completed the exergaming intervention, serum insulin levels decreased by 2% over the course of the study, whereas in the control group, they increased by 21%. Despite the large variation among individuals, this difference still has marginal statistical significance (p = 0.07). Significant outcomes that relate to body composition were also observed, which are discussed in the triglycerides section below.
Serum Triglycerides

Serum triglyceride levels are a risk factor for multiple diseases. Triglycerides are molecules of fat. These molecules can move through the bloodstream together with proteins and cholesterol as lipoprotein aggregates. Serum lipoprotein levels below 150 mg/dL are considered healthy (Cleveland Clinic, 2021), whereas higher levels become risk factors for artery disease, heart attack, stroke, and metabolic syndrome as the level increases. A meta-analysis of 96,000 individuals by the Asia Pacific Cohort Studies Collaboration, for example, found that individuals whose serum triglycerides were in the top fifth of the population had an 80% increased risk of developing coronary heart disease ($p<0.01$) and a 50% increased risk of having a stroke ($p=0.01$) (Asia Pacific Cohort Studies Collaboration, 2004). Triglycerides can also cross the blood–brain barrier, where they can block satiety of hunger by blocking leptin and insulin receptors and even have a negative impact on learning and memory (Banks et al., 2018). A number of studies have shown correlations between elevated serum triglyceride levels and age-based cognitive decline in later years (Dimache et al., 2021).

A study by Araneta and Tanori (2015) showed that a 12-week program of Zumba dance can decrease serum triglycerides and decrease blood pressure in adults with metabolic syndrome disease. In this pilot study, 13 middle-aged women participated in two 60-min Zumba classes per week for 12 weeks. Blood samples were collected before and after the program, after fasting. The participants showed an 11% decrease in serum triglycerides ($p<0.05$) along with 10% and 9% decreases in systolic and diastolic blood pressure ($p<0.05$ for each). These results show that physically active dance classes can have positive effects on both molecular-level and physiological risk factors.

Like Zumba dance, aerobic dancing and step aerobics can also decrease serum triglyceride levels. In a study by Kin Isler et al., (2001), a cohort of 45 sedentary female college students were split into three groups: step aerobics, aerobic dance, and control. The aerobics groups participated in 45-min physical education classes three times a week for eight weeks. The aerobics dance activity incorporated multiple styles of dance into choreographed routines, and participants achieved target heart rates of approximately 60–70% of their heart rate reserve. Morning blood samples were obtained before and after the eight-week sessions, following a 10–12 h overnight fast. The results show that average levels of serum triglycerides had decreased by 29% in the step aerobics group and by 22% in the aerobic dancing group ($p<0.01$ for each), whereas average levels had not significantly changed in the control group.

As was seen in the glucose section above, the effects of dance programs on lipids can sometimes be most beneficial to those individuals whose health is most at risk. A study by Han et al. (2001) evaluated the effect of therapeutic recreational dance movement on healthy and unhealthy elderly men. A cohort of 43 subjects were divided based on current health state to form one group of 31 that had current age-based diseases and health hazards and a second group that was generally healthy. Both groups participated in a 12-week program of therapeutic recreational dance movement, which is not described in detail. Blood samples and other measurements...
were collected before and after the program. While both groups showed substantial increases in muscle endurance, only the unhealthy group showed a significant decrease in serum triglyceride levels (28% decrease, \( p < 0.01 \)), which caused that group to end up with substantially lower levels than those seen in the healthy group.

In other cases, the different impact of dance programs on serum triglycerides in healthy versus unhealthy people can be less clear. The study by Passos et al., (2021), which is described above, investigates the effect of regular recreational aerobic dance on diabetic women. By the end of the four-month recreational dance program, both the diabetic and healthy control groups showed 15% decreases in serum triglyceride levels. Due to high variation among individuals, however, these differences did not meet the criteria for statistical significance.

Changes in serum triglyceride levels do not necessarily correlate with changes in body composition. An example can be seen in the exergaming study by Staiano et al., (2017) that is described above. Among the individuals who completed the 12-week exergaming intervention, total body fat, as measured by full-body magnetic resonance imaging, decreased by an average of 0.7 kg. In contrast, for the individuals in the control group, total body fat increased by an average of 0.7 kg. The difference between these two groups is significant \( (p = 0.01) \), yet no meaningful changes were observed in serum triglyceride levels.

### Cholesterol

Cholesterol is a molecule that is necessary for the formation of human cell membranes and the proper functioning of human cells, yet elevated serum cholesterol is a risk factor for multiple diseases. Since cholesterol is insoluble in water, the body uses low-density lipoprotein (LDL) particles to transport and deliver cholesterol to cells throughout the body. High levels of serum LDL cholesterol, however, cause cholesterol and other lipid molecules to be deposited on the walls of blood vessels and eventually form plaques. These plaques reduce the ability of blood to flow uninhibited through the circulatory system, cause atherosclerosis, and increase the risk of cardiovascular disease, coronary heart disease, and stroke (Saini et al., 2004). LDL cholesterol levels below 100 mg / dL are generally considered healthy for adults (Cleveland, 2020), and health risks steadily increase as levels increase beyond that point (Abdullah et al., 2018). While LDL cholesterol are colloquially referred to as “bad cholesterol,” high-density lipoprotein (HDL) cholesterol, on the other hand, are considered “good cholesterol.” These aggregates, which clean excess cholesterol from the circulatory system by carrying it back to the liver, reduce the risk of atherosclerosis, reduce inflammation, and promote vascular health by activating nitric oxide synthesis pathways (Zhou et al., 2015).

A large-scale study reported by Lin (2021) shows that regular aerobic exercise, either dance-based or otherwise, can correlate with healthier cholesterol profiles that have higher HDL levels. A cohort of 95,247 residents of Taiwan, who were participating in a larger study about genetic-level risk factors, were included in this study. Levels of total cholesterol, HDL cholesterol, and LDL cholesterol were measured from blood serum, and the raw data was processed to normalize for categorical
factors, such as age, sex, and smoking. Individuals who regularly exercised for 30 min three times a week identified themselves through questionnaires. These regular exercisers further categorized themselves into 23 groups based on their main form of exercise. The study found that HDL cholesterol levels were significantly higher in five of these exercise groups: jogging (approx. 5% higher, \( p < 10^{-19} \)), swimming (approx. 4% higher, \( p < 10^{-7} \)), Dance Dance Revolution (approx. 4% higher, \( p < 10^{-6} \)), international standard ballroom dancing (approx. 3% higher, \( p < 10^{-4} \)), and cycling (approx. 2% higher, \( p < 0.001 \)). Other exercise categories, which include walking, mountain climbing, yoga, and weight training, did not show any significant deviations. These results suggest that it is the exercise types that are more aerobic in nature that are the ones that correlate with higher levels of HDL cholesterol.

Other studies have shown that various types of exercise programs, dance or otherwise, can improve cholesterol profiles. A study by Rodrigues-Krause et al., (2018) aimed to compare the effects of dancing, walking, and stretching on older women. 37 sedentary women in their 60 s were split into three groups. The participants completed 60-min sessions three times a week for walking or dancing or one time a week for stretching for an eight-week period. The intensity of the walking and dance sessions resulted in 50–69% of peak VO\(_2\) breathing. Blood samples were collected before and after the intervention, after 8-h fasts. By the end of the intervention the cohort as a whole showed a 10% average increase in HDL cholesterol (\( p < 0.001 \)) and a 6% average decrease in LDL cholesterol (\( p < 0.05 \)). No significant differences, however, were observed between the groups for these measurements. These results suggest that regular exercise programs, even ones composed of mild exercises such as stretching, can significantly benefit health and reduce risk factors.

The study by Kin Isler et al., (2001) that is described above shows that eight-week programs in either aerobic dancing or step aerobics can both positively affect cholesterol profiles in sedentary female college students. The results show that by the end of the study average levels of total cholesterol had significantly decreased by 24% in the step aerobics group and by 17% and in the aerobic dancing group (\( p < 0.01 \) for each). In the control group, a smaller decrease of 10% was observed, but this change did not meet the criteria for statistical significance. Decreases in LDL cholesterol of 12% and 10% were observed in the step aerobics and aerobic dance groups, but these also did not meet the criteria for statistical significance. HDL cholesterol increased significantly in the step aerobics group (17% increase, \( p < 0.05 \)), whereas the 5% increase in the aerobic dancing group did not meet the criteria for statistical significance.

Some studies show that dance programs have more substantial benefits on cholesterol for those individuals who begin with health states that are more at risk. The Han et al. (2001) study that evaluates the effect of a 12-week therapeutic recreational dance movement program on healthy and unhealthy elderly men, for example, shows that it is the group of unhealthy participants in which a change occurs. Before the program, the unhealthy group had 21% higher total cholesterol levels (\( p < 0.01 \)), 24% higher LDL cholesterol levels (\( p < 0.01 \)), and 10% lower HDL cholesterol levels (not statistically significant). By the end of the treatment, the unhealthy group’s average total cholesterol had decreased by 16% (\( p < 0.001 \)), their LDL cholesterol had lowered by 16% (\( p < 0.01 \)), and their HDL cholesterol had increased by 15%
(\(p<0.001\)), which caused all these values to now be analogous to the values seen in the healthy group. A second example can be seen in the study by Passos et al. (2021), that investigates the effect of a 4-week recreational aerobic dance on diabetic women. By the end of the program, the diabetic group’s total cholesterol levels had decreased by 15% (\(p<0.05\)), whereas no change was seen in the healthy control group. These results show that dance programs can help reduce health risks by correcting unhealthy cholesterol levels.

**Summary of Molecules**

Dance/movement therapy can lead to increased serum nitric oxide levels. In this case, the results of the dance activity parallel similar effects that are observed from moderate-intensity traditional exercise. Nitric oxide is a signal molecule that is involved in many biochemical processes, and this change in nitric oxide level can positively impact cardiovascular health, for example by decreasing arterial stiffness.

While dance activities have been shown to affect the levels of serotonin, dopamine, estradiol, and cortisol, it can be complex to interpret how these changes connect to health and disease because these hormones impact complex signaling pathways within the body. Serotonin levels in the nervous system are known to positively impact cognitive functions, positive mood, and satisfaction. While dance/movement therapy can lead to increased serum serotonin levels and reduced depression scores, questions remain about the complex relationship between serotonin levels in the blood versus those in the brain. This complexity leads to challenges of obtaining the relevant biochemical measurements. Dopamine is associated with neurodegenerative diseases and neurological diseases, but these relationships are complex and challenging to interpret based on the current understanding of these diseases. Although dance/movement therapy can lead to decreased serum dopamine levels, it is difficult to interpret how this change relates to observed decreases in depression scores. Square dance activities can lead to increased serum estradiol levels and increased bone density. Since estradiol levels naturally decrease with age, this change can help prevent osteoporosis in older women. In contrast, for younger women, exercise activities can help decrease peak estradiol and progesterone levels as well as premenstrual syndrome symptoms. These complexities present a cautionary warning about trying to draw health conclusions directly from molecular data without a full understanding of the context. Dance/movement therapy programs can lead to decreases in morning cortisol levels and to changes in daily cortisol cycles. They also can lead to improved mental health scores. Collecting and interpreting cortisol measurements must be done carefully, however, because its levels oscillate substantially throughout the day. Sessions of Argentine tango can lead to decreased cortisol levels, whereas sessions of African dance can lead to temporary increases in cortisol levels. These increases still correlate with decreased reported stress, however, because it is long-term cortisol levels, as opposed to spikes during activity, that are important.

Dance activities can impact serum levels of glucose, triglycerides, and cholesterol. These molecules enter the body as food components, but their serum levels are
then impacted by complex biochemical and cellular processes. Chronically elevated serum levels of these compounds are well known to correlate with a variety of metabolic and cardiovascular disease outcomes. Aerobic and exergaming dance activities can lead to decreased levels of serum glucose. Zumba, aerobic, and recreational dance activities can lead to decreases in serum triglyceride levels, as well as positive physiological outcomes such as decreased blood pressure and increased muscular endurance. Regarding cholesterol levels, it is important to differentiate between HDL cholesterol, which increases health, and LDL cholesterol, which increases disease. HDL cholesterol levels can be increased and LDL cholesterol levels can be decreased by a variety of different dance activities. In many cases, these changes are seen most dramatically in those who begin with poor health states.

**Conclusion**

Despite the various challenges of performing these complex experiments and interpreting their results, the aggregate body of work that has been produced by a wide collection of researchers, and that is continuing to be expanded upon by ongoing work, shows that dance activities can have many of the same health benefits as other types of exercise. For many individuals, dance is a more engaging and enjoyable activity than traditional exercise routines, which causes dance to be an important option for minimizing the negative impacts of disease states and for proactively promoting the positive impacts of health. As more and more details are revealed about how particular dance activities connect to specific details of health and disease, we anticipate that more and more individuals and healthcare providers will choose to incorporate dance/movement therapy into treatment regimes and also to proactively incorporate dance activities into their daily lives.

**Author Contributions** Both authors contributed to gathering information, analyzing results, and writing the manuscript.

**Funding** Funding for this work was provided by Clark University. ILN acknowledges a Steinbrecher Fellowship, provided through Clark University.

**Declarations**

**Conflict of interest** The authors declare that they have no conflict of interest.

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**Publisher’s Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

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