Research Article

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Biomechanical aspects of Tai Chi Chuan countermeasure against health threats during spaceflight

Abstract

In support of NASA's plan to establish human settlements on the Moon and Mars in the near future and the emergence of cutting-edge artificial intelligence as a tool for better health care, we look for ways to help astronauts stay physically and mentally healthy during a long and stressful trip. After reviewing existing aerobic and strength exercise methods available to astronauts, we propose that traditional Tai Chi Chuan (TCC) or Taijiquan can serve as a non-invasive intervention to help astronauts maintain physical and physiological integrity and cope with the impact of microgravity during and after spaceflights. Biomechanical aspects of TCC in terms of neuromuscular and musculoskeletal conditions are presented based on a review of evidence from the scientific literature that defines physiological responses associated specifically with the practice of TCC as relevant to space mission-related effects of microgravity on human physiology. This article provides a comprehensive review and description of the TCC biomechanics and their health influences in microgravity. The mysterious Chi (or Qi) of TCC is scientifically defined as kinesthetic sensations of position, movement, and force of muscles, tendons, and joints throughout body segments in kinetic chain motions. These sensations can be used to judge the correctness of TCC trainings as a countermeasure against lowered gravity to improve proprioception, kinesthesia, and mind-body coordination for astronauts. This study has far-reaching implications for the integration of TCC practices in complement with the effectiveness of existing countermeasure approaches, and provides direction for future research that might bridge the knowledge gap in improving exercise countermeasures for human spaceflight.

Keywords: artificial intelligence, Tai Chi Chuan, international space station, Tai Chi exercise, advanced resistive exercise device, electroencephalogram

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Introduction

Cutting-edge artificial intelligence (AI) could play an important role in predictive and preventative healthcare for space travelers such as sensor development, health data analysis, human behavior assessment, and human performance intervention. Equally possible, an ancient Chinese martial art called Tai Chi Chuan (TCC) or Taijiquan may help remediate the health impact of microgravity as well. As NASA works toward its long-term goal of establishing human settlements on the Moon and Mars, the advancement of AI and the recognition of TCC can help NASA make the dream a reality. These exciting expectations have rekindled our interests to look into the health issues in outer space under a multitude of gravitational forces.

The gravity levels on the International Space Station (ISS), the Moon and Mars amount to 90%, 16.6% and 38%, respectively, of Earth's gravity. However, during the trek in outer space to Mars, the gravity becomes almost zero. Body systems influenced by microgravity are the neurovestibular, cardiovascular, musculoskeletal, metabolic, and immuno-hematological systems.[1] The changes associated with these systems occur when entering to microgravity (initial adaptation), spending prolonged time in microgravity, and returning to Earth (re-adaptation). Since mechanical loading under these microgravity environments will not be sufficient to maintain physical and physiological integrity of astronauts, exercise countermeasures become crucial for long-duration spaceflights and settlements. Design of effective exercise programs in limited area are difficult but essential for astronauts to alleviate adverse health and mental impacts such as space motion sickness, sensorimotor coordination disorders, sleep problems, bone loss, muscular atrophy, cardiovascular deconditioning, anemia, and immunodeficiency.[2,3] Given the challenges and restrictions to setup of costly exercise equipment and to effectiveness of standard human-to-machine exercises under reduced gravitational forces, other non-intrusive countermeasures should be explored. TCC, an ancient martial art to promote harmony between body and mind, has been performed in lowered gravity by Chinese astronauts on the Shenzou 10 and 11 spaceflights, respectively.[4] The Chinese astronauts found that a TCC routine as specifically designed for space exercise was helpful in soothing emotions. Unfortunately, no detailed information has been revealed because of national security concerns. This article seeks to apply the knowledge of biomechanics of TCC as an effective exercise stimuli that may maintain crew health and safety while being fun and easy for astronauts to perform during a long-term space journey.

Characteristics of Tai Chi Chuan

The traditional TCC as an internal martial art emphasizes training requirements for central stability, relaxation, tranquility, slow motion, and integrity. Time Magazine has called TCC "the Perfect Exercise" as it combines intense mental focus with deliberate, graceful movements that improve health, agility, and balance particularly for the elderly.[5] TCC's special mindset helps visualize the connection and integration of all parts of the human body. The internal training of TCC is obviously different from those of external martial arts and common physical exercises. TCC's self-defense ability is attributed to "internal force" which can only be obtained by correctly conforming to the Tai Chi Classics.[6] The Tai Chi Classics were historically strictly enforced by the traditional TCC training, but are regrettably only loosely followed nowadays by many popularized TCCs--commonly called Tai Chi Exercise (TCE). Given the ancient nature of TCC knowledge, the Tai Chi Classics were written in metaphors and can only be comprehended by diligent practitioners who advance through special training led by experts. Thus many people may find it difficult to comprehend TCC's moving meditation at first, but persistent practice conforming to the principles of Tai Chi Classics should prove helpful. Since most TCC-related medical studies were unfortunately based on TCE rather than traditional TCC, the potential health benefits of TCC may not be fully understood.

Tai Chi Chuan benefits for astronauts

To mitigate fitness loss during spaceflight, aerobic and strength exercises are the most common countermeasures available to astronauts to date. Normally, 2.5 hours/day and 6 days/week are allotted in each crew member's schedule for exercise to be performed on highly specialized hardware such as a bicycle, a treadmill, and a weightlifting machine called the Advanced Resistive Exercise Device (ARED).[7] When aerobic and strength exercise are considered in close proximity, strength should precede aerobic stimulus.[8] Nevertheless, the effectiveness of these exercise approaches for maintaining bone, muscle, and aerobic fitness has not been fully demonstrated due in part to the low reliability of the devices flown to date.[1]

Whereas western fitness is often focused on developing individual parts of the body, such as legs through biking, or chest and arms through weightlifting; TCC is designed around full-body action so that the body works more efficiently and thus performs at its best. TCC is known as a meditation in motion to constantly seek tranquility while moving slowly and softly using relatively little inertia and gravitation. As a non-invasive intervention to assist in adaptation in microgravity and re-adaptation back to 1G gravity, TCC may complement and enhance the effectiveness of those countermeasures currently prescribed for astronauts. Therefore, TCC can serve as a supplemental strength training method for astronauts to enhance sensory receptors of joints and muscles and to reduce the metabolic rate. In addition to restoring muscle balance and joint stability, TCC's capability of body integration and mind coordination can further promote the mental and physical health of astronauts through relaxation, tranquility, softness, and slowness.

The TCC training for astronauts should logically begin with pre-flight learning of essential principles and diligent practicing thereafter for establishing a solid baseline prior to continuous workout during and after spaceflights. During spaceflight, the required TCC training will be provided in the later sections of this article. More importantly, the TCC breathing stimulation and mental relaxation can be conducted at any time and in any situation of standing, moving, walking, sitting, or lying down.

Tai Chi Chuan practices in space

The traditional TCC we recommend for training astronauts is the Cheng Man-Ching (CMC) style TCC, also known as the 37-Posture Yang-style TCC as simplified by Master Cheng Man-Ching. The CMC-style TCC is performed in "middle frame" to let the joints become loose and movable and to build internal strength through full use of every part of the body. Thus, the principles for excellence in practicing CMC-style TCC can help practitioners comprehend the transformation between insubstantial (Yin) and substantial (Yang), develop calmness and stability, and attain suppleness for self-defense.

With its unique biomechanical character, the traditional TCC can help astronauts and space travelers more specifically in the following two interacting aspects: neuromuscular control (neural elements) and musculoskeletal control (muscular, osseous and ligamentous elements).

Neuromuscular control of Tai Chi Chuan

When learned correctly and performed regularly, TCC can be a positive neuromuscular control to manage stress, improve sleep, and relieve nausea and motion sickness in spaceflight.

One of the fundamental principles of the Tai Chi Classics to ensure corrective and effective performance is the ability to achieve "relaxation" through electroencephalogram (EEG) brainwave measurement.[9] TCC is known as "meditation in motion" because both mindfulness and relaxation are required as the foremost part of traditional TCC progressive training. The relaxed physiological state associated with deliberate control, involving inferior frontal gyrus and supplementary motor areas, is hypothesized to be the opposite of the stress response.[10] Each cultivated TCC movement depends not only on task-focused intelligence, but also on relaxed mind-wandering, reflection, free association, and creativity. In other words, TCC movements are mediated by the default mode network in the brain while the mental state of operation is mediated by the task-positive network.[11] The TCC movements with unique moving meditation also relate to activating the parasympathetic and quieting the sympathetic nervous system, where the parasympathetic nerve activation is vital to help astronauts decrease stress and anxiety during the space mission. More specifically, TCC can help astronauts manage stress physiologically through both the general auto-regulatory self-healing mechanism and the endogenous auto-regulatory signaling mechanism that are linked to the brain's innate reward and motivation circuitries (limbic system).[12] Medical studies showed that individuals who practiced meditation daily had lower blood levels of epinephrine, norepinephrine, and cortisol.[13] Meditation also led to lower respiration rates and heart rate as well as better blood flow to the brain, indicating less constriction of blood vessels.

In spaceflight, sleep insufficiency and worse sleep quality are common problems for astronauts. Studies demonstrated that some of the astronauts' sleep problems in space were often caused by uncomfortable ambient temperatures, higher noise levels, uncomfortable sleeping bags, or the absence of familiar proprioceptive cues.[14,15] Studies indicated that TCC was able to alleviate astronaut's sleep problems in a confined space environment by improving mood and reducing the low frequency activity of the EEG signals.[4] As a countermeasure to sleep issues, TCC intervention may modulate the functional connectivity between prefrontal cortex and medial temporal lobe as the possible mechanisms to improve sleep.[16]

Transitioning from one gravity field to another with less gravity influence leads to central fluid redistribution, which in turn activates Henry–Gauer and related reflexes.[17] In microgravity, the distribution of blood changes with more in the upper torso and less in the legs. At landing, the gravity pulls blood downwards in an upright human body to cause light-headed feeling. Since TCC practices have potential beneficial effects on cerebral hemodynamics as well as heart and brain blood circulation, it is possible that TCC may provide relief from the nausea associated with early exposure to microgravity.[18,19]

A new comprehensive study revealed that mitochondrial dysfunction may largely contribute to health and performance challenges faced by humans in space.[20] Significant increases in both N-acetylaspartate to creatine ratios and phosphocreatine recovery rate were reported by a pilot study on brain metabolism and muscle energetics in older adults with a short-term TCC training.[21] This

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suggests that TCC may effectively promote neuroplasticity, accelerate adenosine triphosphate synthesis, and improve muscle mitochondrial function; thus TCC should be considered as a countermeasure to help mitigate the mitochondrial stress for future space travelers.

Musculoskeletal control of Tai Chi Chuan

Current strength exercise available to astronauts regarding the musculoskeletal system largely focuses on strengthening single areas of the body or single group of muscles. On the other hands, TCC has more similarities to a full-body strength building routine. During TCC practices, the musculoskeletal system along with the nervous system and the cardiovascular system, all work together to transfer energy or force from the lower limbs through the trunk to the upper limbs.

Relaxation training of TCC can help astronauts reach a feeling of the body sinking down to the feet and to further penetrate into the ground, which is partly a dynamic function of the gravity force on Earth or on the ISS after necessary adjustments. In other words, the sinking feeling of conforming to gravity is a result of reducing both body stiffness and sympathetic arousal. According to one of the Tai Chi Classics: "*The Hsin (mind) mobilizes the Chi (sensation) and makes the Chi sink calmly*".[22] Subsequently, the ground reaction force (GRF) and torque can be directed as internal force to a point above the center of human body mass. This synergistic reaction throughout three anti-gravity kinetic chain segments (lower limbs, spinal, upper limbs) is instructed in Tai Chi Classics as: "*The motion should be rooted in the feet, released through the legs, controlled by the waist, and manifested through the fingers*".[23]

The ability to "sink" is a prerequisite to cultivating the internal force through synchronization of body musculoskeletal elements. The relaxation of practicing TCC brings a feeling of the lower-body sinking and becoming heavy while the upper-body becomes light and agile, as substantial (Yang) and insubstantial (Yin) complement each other at the same time. As indicated in another Tai Chi Classic: *"Effortlessly the Jin (internal force) reaches the head-top, while letting the Chi (sensation) sink to the dan-tien (abdomen). Don't lean in any direction. The Jin will suddenly appear and suddenly disappear"*.[24]

This implies that TCC's effortless action -- when manifested by diaphragmatic breathing along with correct postural alignment, mindfulness meditation, and rooting in connection with the ground beneath the feet -- can help one reach a state of effortless action. The functions of the diaphragm do not stop locally in its anatomy but affect the whole body system, which can help not only stimulate the phrenic and vagus nerves for regulating peripheral nervous system but also strengthen core muscles for proper load balance of pelvis and spine throughout the kinetic chain.[25] In other words, the triple function (breathing, peripheral nerve regulation, and core stabilization) of the diaphragmatic breathing is a vital part of traditional TCC training. While sinking the "chi (breath)" down to the dan-tien (abdomen), the diaphragm serves as the roof of a ''muscular cylinder'' of the core, the pelvic floor serves as the floor, and the transversus abdominis and multifidus muscles serve as the wall. Contraction of the diaphragm increases intra-abdominal pressure within the muscular cylinder, thus adding to spinal stability.[26] Additionally, through the diaphragm's fascial and connective links, the TCC diaphragmatic breathing can activate the thoracic and lumbar erectors, quadratus lumborums in the lower back, and the psoas muscle that crosses the rim of the pelvis to connect the legs to the spine.[27] These are all important muscles in moving and stabilizing the spine. In fact, TCC has been proved to have a significantly greater effect on lower-limb neuromuscular function in comparison to other evidence-based core stability training programs.[28]

Maintaining strong core muscles by TCC can be helpful for astronauts in a microgravity environment to move equipment and supplies on the ISS and to perform Extra-Vehicular Activities in space. The traditional TCC training with diaphragmatic breathing should begin in the pre-flight stage for astronauts to learn how to activate the diaphragm together with the transversus abdominis, multifidus, pelvic floor, quadratus lumborums, and psoas muscles. When this has been mastered, more advanced postural training can be added to learn how to further enhance lumbar-pelvic stability by recruiting internal oblique and deep transversospinalis prior to any attempts of moving the limbs by themselves. This is what the renowned Master Cheng Man-Ching used to say: "*TCC is without hands, hands on is not TCC*".[29]

It should be noted that body stability is a function not a structure. Tightening and working the abdominal muscles and back muscles by the specialized equipment designed for astronauts to exercise on the ISS, such as ARED and the Combined Operational Load-Bearing External Resistance Treadmill, seem to treat the torso like a hollow tube. Overly strong activation of the abdominals would interfere with the diaphragm's ability to contract properly and thereby reduce stabilization. As it is still unknown regarding how much aerobic and strength exercise is required for an astronaut's space mission success before and during spaceflight, performing the traditional TCC including diaphragmatic breathing can help out in any situation and at any time.

The feeling derived from sinking, also known as rooting, comes not only from having good balance but also from connecting all parts of the body to the ground. A strong and deep root from proper TCC training is obtained by understanding postural positioning and alignment in line of gravity, reducing the load of joint surfaces, and transferring body weight to the feet with minimal energy expenditure by muscles. The rooting is accomplished by placing the body weight at a desired position such as the "bubbling well" to achieve Zhong Ding (central equilibrium), which is the most critical element of the basic thirteen postures of TCC or also known as Eight Gates and Five Steps.[30] The bubbling well is located one third of the way from the base of the toes to the edge of the heel in the sole of the foot between the metatarsals of the 2nd and 3rd toes.

TCC movements for astronaut's physical and mental training during the spaceflight can be conducted through mindful awareness of each movement under artificial gravity conditions if applicable, by wearing comfortable harnesses attached to the floor that can apply a force equal to the body weight, or by simply fixing the feet to the floor for few footsteps as appropriate to create resistance in microgravity. Studies have found that TCC movements have greater anteromedial plantar loading and larger center of pressure displacements both in the direction of anteroposterior and mediolateral when compared with normal walking exercise.[31] The plantar pressure characteristics in TCC movements may intensify the plantar cutaneous tactile sensory input from the metatarsal head area, increase the muscle strength of the lower extremities, and subsequently improve balance control.

When the lower-body is correctly balanced and the whole body parts -- particularly the ankles and feet -- are sufficiently relaxed through the nervous system regulation, the sensory feedback from activation of plantar cutaneous mechanoreceptors can better manage the reaction of the ground.[32] In TCC movements, the change in the contraction of the lower leg muscles often precedes the contraction of the upper body muscles. Almost all loads on the muscular skeletal system can be modeled and understood by simple levers. Since muscle attachments are close to the joint centers, small contractions of the muscle can produce large movements at the end of the levers producing a mechanical advantage in the motion of the limbs.[33] More importantly, the TCC movements involve a different group of core muscles and require a relatively longer duration of activation of these muscles. In order to achieve smooth transitions from one posture to another, each muscle needs to serve as both a prime mover and a stabilizer, changing between concentric and eccentric actions.[34]

While living and working in microgravity, the loss of gravity sensory information leads to the deterioration of bones, joints, and antigravity muscles including the gastrocnemius and soleus.[1] Although astronauts exercise rigorously, the antigravity core muscles may not be adequately recharged. The influence of TCC's diaphragmatic breathing on the central nervous system can activate the skeletal musculature via influencing motor expression. It can also move the brain mass, oscillate the neural network, and stimulate the blood circulation.[25] During non-exercise hours, TCC can also be readily performed by astronauts to bridge the gap by strengthening the core muscles that evade the traditional aerobic and strength exercises. Data from spaceflights revealed that bone loss occurs mainly in the femur, tibia, calcaneus, and vertebrae. Post-flight TCC practices may be effective for recovery of bone mineral density loss at the regions of lumbar spine, proximal femur neck, and distal tibia.[35] Another study also revealed that regular TCC exercise may attribute to higher bone mineral density and better neuromuscular function in early postmenopausal women.[36]

Insights into the musculoskeletal control by TCC can be further exemplified using the concept of kinetic chains to indicate how the TCC movements neurologically interconnect all skeletal and muscular systems in the microgravity environment. Understanding kinetic chains allows us to build a functional foundation from the inside out, taking into consideration all pieces of the chain; bones, muscles, and joints included. On Earth or on the ISS in low Earth orbit, traditional TCC movements conducted by astronauts involve both closed kinetic chain (CKC) and open kinetic chain (OKC) motions.[37] Traditional TCC can be adaptive and performed by astronauts with primarily OKC motions while sitting or lying down. On the Moon, Mars, or in microgravity where the gravity force is significantly reduced; TCC movements can be performed with OKC motions only.

Performing TCC as CKC motions when the feet are connected to the ground, kinetic actions occur across multiple lower extremity joints before transferring through pelvis and spine to upper extremity joints. For instance, when the body weight (even reduced in microgravity) can be placed at the bubbling well and the fulcrum is positioned at the ball during the TCC performance, contracting the calf muscles (gastrocnemius, soleus, plantaris) can control the upward movement via a second-class lever system. As the activation sequence is initiated from a firm base of support, the resultant force from the moment of ground reaction is subsequently assisted by the TCC diaphragmatic breathing and transferred through the links to the more mobile distal segments.

Performing TCC as OKC motions on Earth or the ISS while seated or lying down, the distal segments (arms or legs) are free to move in space, the proximal segments (lumbar spine and thoracic spine or lumbar spine and hip joints) are fixed as the focuses of the OKC motion. The same OKC motion situation is applicable to TCC performance on the Moon, Mars, or in weightless environment. In these situations, the activation sequence is initiated from the diaphragmatic breathing together with stimulation of the lumbar core muscles prior to engaging in the distal limb movements.

Accordingly, as assisted by appropriate adjustments to prevent floating, TCC can help strengthen both the lower and upper extremities and also the core muscles of the back and abdomen. TCC's relaxation and mindfulness along with diaphragmatic breathing and kinetic chain movements can offer an effective control of musculoskeletal systems.

Cultivation of Chi (Qi) and internal Force (Jin)

In traditional Chinese medicine, Chi (or Qi) is believed to be a vital force forming part of any living entity. However, the metaphysical concept of Chi has not been scientifically defined. According to the TCC Classics, the mind directs the Chi and the Chi mobilizes the body. The internal force (or Jin) is released while sinking, relaxing, and aiming it at one direction.[38]

Performing traditional TCC in a CKC situation, the transfer of internal forces along with accompanying momentum and kinetic energy occur through four body segments from feet to hands.[39] These four segments are legs (ankles through knees to hips), waist (hips through pelvis/sacrum/lumbar to thoracic spine), chest (thoracic spine through shoulder blades to shoulder joints), and arms (shoulder joints through elbows to wrists), respectively (Figure 1). The leg and waist segments are relatively more important than the other two in accordance with the Tai Chi Classics: "*if the timing and position are not correct, the body becomes disordered, and the defect must be sought in the leg and waist*".[23] As the first stage to boost the internal force (Jin) vertically upward, the leg segment takes the mechanical advantage of the vertical GRF and torques amplified by the second-class lever system mostly by plantarflexion or occasionally by dorsiflexion at the ankle.

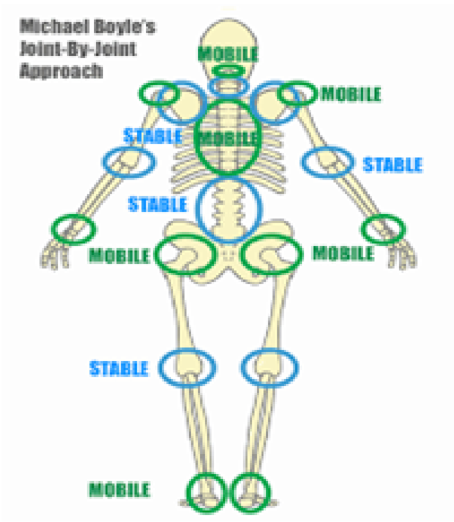

Figure 1 Joint by joint approach of Michael Boyle.

Therefore, while enhancing the internal force, TCC practitioners must engage the lower body and strong core muscles of the torso rather than the arms and hands. During the bottom-up kinetic-chain movements, besides the GRFs, rotating the body segments to create additional angular momenta help drive the arms forward naturally with little muscular effort from the arms. The angular momentum, developed by the coordinated action of body segments, transfers to the linear momentum of the hands at impact.

Given the fact that the human body mass and geometry will not change in the space or on the ground, rotational TCC movements can be mathematically substantiated to indicate the efficacy regardless of reduced gravitational forces in microgravity.

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The linear and rotational forces generated from three-dimensional TCC movements involve the rotational angular momentum, $\tilde{L}$ as:

$$\tilde{L} = \bar{R} \otimes \bar{P} , \quad (1)$$

Where $\otimes$ is a vector outer product given the axial vector $\tilde{L}$, thus the torque $\tilde{T}$ is defined as:

$$\tilde{T} = \bar{R} \otimes \bar{F} = \bar{R} \otimes \frac{d\bar{P}}{dt} = \frac{d(\bar{R} \otimes M\bar{V})}{dt} - \frac{d\bar{R}}{dt} \otimes M\bar{V} = \frac{d(\bar{R} \otimes \bar{P})}{dt} - M\bar{V} \otimes \bar{V} = \frac{d\tilde{L}}{dt} , \quad (2)$$

The linear velocity can be defined as $\bar{V} \equiv \frac{d\bar{R}}{dt}$, which is related to the angular velocity $\vec{v} = \tilde{\omega} \otimes \bar{R}$; thus $\tilde{L}$ in Eq. (1) becomes:

$$\tilde{L} = \bar{R} \otimes \bar{P} = \bar{R} \otimes M\tilde{\omega} \otimes \bar{R} = M\left[\left(\bar{R} \otimes \bar{R}\right)\tilde{\omega} - \left(\bar{R} \otimes \tilde{\omega}\right)\bar{R}\right] = MR^2\tilde{\omega} \cong I\tilde{\omega} , \quad (3)$$

Assuming all mass parts are rotating at the same angular velocity but with different distance R_i , thus we can compute statistically the total moment of inertia as Gaussian variance of distances below:

$$< I >_{Gaussian} = \sum_{i=1}^{n} m_i R_i^2 \cong \sum_{i=1}^{n} \frac{M}{n} R_i^2 = M \frac{1}{n} \sum_{i=1}^{n} R_i^2 \cong M < R^2 >_{Gaussian} . \quad (4)$$

Eq. (4) substantiates the quadratic effect of the radius of gyration $< R^2 >_{Gaussian}$ from rotational arm and trunk movements to indicate the TCC efficacy in space regardless of reduced gravitational forces.

Understanding precisely the role of each muscle group during TCC practices is still the object of research. However, the net joint forces and torques as a function of body segments and GRFs during TCC movements can be determined by applying the Newton-Euler equations of motion for inverse dynamics. Since the Chi can be sensed, we would like to define the Chi scientifically as "kinesthetic sensations of position, movement, and force of muscles, tendons, and joints throughout body segments in kinetic chain motions".[40] Contrarily, the energy is a scalar quantity, has no direction, and cannot be felt. The inverse dynamics and kinematics enable us to briefly delineate the resulting kinesthetic sensations of position and movement of the body parts with respect to each other and of muscle forces and efforts in kinetic chain motions. Nonetheless, performing the traditional TCC can enhance the joint, muscle, and ligamentous torques by stimulating the neural connectivity of the brain and the neuromuscular sensitivity for physical and mental health on the ground and during the space travel. The daily practices of TCC must pay particular attention to cultivating the internal force at alternative stages of "stability and acceleration" while cultivating the Chi to foster the kinesthetic sensations and mind-body connection.

Conclusion

The level of fitness necessary for performing required space mission tasks remains an unanswered and pressing question for scientists and spaceflight physicians. To mitigate fitness inadequacy during spaceflight, based on evidence from the scientific literature that links various neuromuscular and musculoskeletal controls used for TCC performance, we hypothesize that TCC can serve as a promising countermeasure readily available to astronauts beyond existing aerobic and resistance exercise. Learning and practicing traditional TCC capable of developing internal force is crucial, and the training should start early in the pre-flight training period and continue through post-flight. The mindfulness and relaxation aspects of TCC performance can be beneficial to mitigate the motion sickness, mood and stress, sleep disturbance, and post-flight orthostatic intolerance. The core stability and kinetic chain aspects of TCC performance can be beneficial to strengthen bones, joints, and muscles. There is a hierarchy that we must appreciate--muscles, joints, and tissues are at the mercy of the nervous system. We are physical bodies with emotions, thoughts, and feelings. TCC's meditation in motion along with diaphragmatic breathing and synergistic effects should offer a valuable tool for both neuromuscular and musculoskeletal controls. Scientifically, our new definition of the Chi should facilitate the training for cultivation of both the Chi and the internal force. The quadratic effect of the radius of gyration in rotational TCC movements is mathematically substantiated to indicate the TCC efficacy regardless of reduced gravitational forces in space. Our biomechanical analyses and hypotheses also reflect the need for more evidence that TCC can be an effective countermeasure to improve proprioception, kinesthesia, and mind-body coordination for astronauts. Due to the importance of mankind's migration to space, further supports to verify our hypotheses are hereby recommended.

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Conflicts of interest

None.

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T. Julian Chu (朱殿蓉) has been teaching Yang-Style Tai Chi Chuan (TCC), traditional Yang-Style Tai Chi Weapons (Sword, Saber, Staff), and Push Hands in U.S. over 40 years. He is a senior student of Master Benjamin Lo (羅邦楨) who is a senior student of Professional Cheng Man-Ching (鄭曼青). He has published over ten TCC articles in TCC Journals of Taiwan, received a number of TCC awards, and organized many TCC workshops and Push Hands activities over 30 years. Academically, he has published over 50 scientific articles in professional journals of Chemical Engineering and Environmental Engineering, respectively; as well as the MedCrave Online Journal of Applied Bionics and Biomechanics. He worked at the Tennessee Valley Authority and then at the Department of Army over forty three years as researcher and national program manager, respectively; and served on committees for several professional journals. He received a number of achievement awards including two U.S. Army Meritorious Service Medals and two U.S. Superior Civilian Service Medals.

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