BIOMEDICAL AND PSYCHOSOCIAL FACTORS INFLUENCING RETIREMENT FROM SURGERY

AN ABSTRACT
SUBMITTED ON THE 11TH OF DECEMBER 2016
TO THE
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IN PARTIAL FULFILLMENT
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OF THE
SCHOOL OF MEDICINE
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FOR THE DEGREE
OF
DOCTOR OF PHILOSOPHY
BY

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ABSTRACT

There is a gap in biomedical and psychosocial research on surgeons nearing retirement. Coupled with an impending shortage projected in the next decade according to predictive models, it would benefit the medical community to effectively retain as many surgeons on the brink of retirement as possible. This is necessary to train and mentor incoming surgeons and to ease the projected workload due to the aging US population.

While surgeon assessment is required every few years through peer review, this process can be subject to bias at several levels. Surgical thresholds of performance beyond which one should consider retirement are not established. A biometric evaluation of the requirements of a skilled task is not tenable with current technology. This dissertation research has two aims: one biomedical, to determine the efficacy of muscle cooling on fatigue and tremor in late career professionals using a cooling garment and the other, psychosocial, to determine whether late career surgeons with pronounced physiologic tremor and fatigue embody ageist stereotypes as a consequence of perceived and real physical performance changes.

It was hypothesized that muscle-cooling therapy would increase time to functional fatigue and reduce amplitude of physiologic tremor compared to ambient temperature exposure. In an initial study on musicians, a significant reduction in tremor was observed using a cooling garment but functional fatigue was not significantly altered. In a second study with older surgeons, cooling was associated with a significant reduction in tremor amplitude in two axes, up/down ($t(8) = 1.89458$; $p<0.05$) and back/forth ($t(8) = 1.7712$; $p<0.05$). Tremor amplitude was reduced in novice surgeons but the effect was

not significant. Time to fatigue and suture time improved in both cohorts with muscle cooling, but did not reach significance.

For the second aim it was hypothesized that late career surgeons with a higher awareness of age stigma consequently fatigue more quickly and have more pronounced physiologic tremor. Both cohorts had an age identity significantly younger than their actual age. Age stigma consciousness measures were relatively low and scores for occupational self-efficacy were high, no significant correlations were found between these measures and tremor or fatigue.

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Chapter 1. Introduction

Experienced, older surgeons

Investigation into proactive methods for determining thresholds of cognitive and physical functionality beyond which a surgeon should not operate will address the research gap that presently exists. Surgical journal editorials and hospital administrators have repeatedly called for the collection of cognitive and biometric research on older surgeons to investigate physical, cognitive, and medical competency thresholds of performance beyond which a surgeon should retire from operation. Hospitals currently have a reaccreditation process for older surgeons that include cognitive testing in addition to self and peer review that can be subjective and biased. However, a review of several studies called for more external assessment and objective methods and also cited physicians' limited ability to self-assess (Davis et al, 2006). Survey data about surgeon burnout, nights on call, and the medical education process is substantially more available than any biometric data on surgeon aging. Additionally, the survey data available is almost all cross-sectional in nature, with very few studies focusing on the physical and psychological process of surgeon retirement. While cognitive testing may help to gauge a surgeon's performance as they age, the biometric data will ideally allow the medical community to develop methods of extending the careers of surgeons through the application of biomedical engineering research and development. These applications will likely draw from existing research that assist athletes and other high performance professionals. One application that has been in use for years is intermittent muscle cooling to reduce athletic fatigue. While the exact underlying muscular mechanisms of cooling's reduction of fatigue are unclear, limited data points to family of thermally activated transient receptor potential cation channels located in skeletal muscle. Other alternatives include pharmacologic interventions such as beta-blockers, which are known to reduce tremor. However, it would be best to not have surgeons resort to medication, especially in older surgeons who might already be on a multiple drug regimen for a preexisting condition.

Novice surgeon training

In order to meet the medical demands of the growing demographic of aging patients there should be a proportionate increase in the North American Medical School graduates and residents. Increasing medical school enrollment and residency program opportunities will require an expansion of existing mentoring programs within the current surgical workforce. The Resident Physician Shortage Reduction Act of 2009 initially proposed a 15% increase in overall residency positions funded through Medicare and also specified preference for hospitals which prioritize primary care and general surgery physicians (Etzioni et al, 2011). However, this act was not passed and was recently resubmitted (S. 1148) without the reference to surgery and little hope of passing committee. Congress wishes to pursue funding more surgical positions; however, the current uncertainty in the US economy is limiting growth in surgical and general residency programs. If passed, the bill would add 15,000 resident slots from 2017-2021 (3,000 each year). Each year, half the allotted spaces would be reserved for areas with a projected shortage. Older surgeon mentorship of residents in the coming decade is also of pivotal importance. The significance of mentoring in a surgeon's career path is especially influential during the junior year of residency, and as such, more practicing surgeons should be involved in mentoring the next generation (McCord et al, 2009). A parallel situation exists in European Union member nations, where the population of physicians 45 years and older increased more than 50% between 1995 and 2000 (Rechel et al, 2013). Additionally, in 5 EU member states almost 50% of the nursing profession is 45 years and older, so the aging of the healthcare workforce could be universal to the entire (OR). While there has been an increase in the number of students entering and completing medical school, there has not been an equivalent increase in residency positions, creating a bottleneck and competition situation where not all potential residents are 'matched' on Match Day. A total of 5.6% of medical school seniors went unmatched on Match Day 2014 (LaPaglia et al, 2015). The lack of available residency positions might be discouraging future physicians to apply to medical school or consider medicine as a profession.

Population demographics in the United States are changing so rapidly that someone turned 65 while you were reading this sentence (every 6 seconds, Aljazeera America). Life expectancy, as of 2011, was an average of 78.8 years (81.2 for females, 76.4 for males) (Colby, 2015). In the US, 3 million adults will turn 65 this year and every year until 2029 (Barr, 2014). According to the US Census, those over 65 will increase from 46 million in 2014 to 74 million in 2030 and 98 million in 2060 (an increase of 112%), whereas the age range from 18-64 is projected to increase less than 20%. The population demographic shift toward a larger proportion of older citizens is not limited to the United

States. The aging of the population will also be observed in EU member nations, partially due to lower fertility rates but mainly as a consequence of the increase in life expectancy, with the population of those 80 years and older expected to triple between 2008 and 2060 (Rechel et al, 2013). However, with the recent and drastic influx of refugees and immigrants across Europe, this dynamic will likely change significantly.

Longer life expectancy coupled with the larger population of older adults will change the political, professional, and medical landscape in this country. Those who can work until their later years might also be a primary caregiver of a spouse or relative, and a large percentage of these older adults will suffer from chronic, costly medical conditions such as elevated blood pressure and chronic obstructive pulmonary disease (COPD). The Institute of Medicine estimates a need for “1.6 million new (physician and surgeon) positions by 2020 and we're not on a path to meet that need by any stretch of the imagination" (Barr, 2014). There are several things to consider for the future of surgery, including the availability of social welfare and retirement programs, the rise in need of medical care for older adults, the aging of the current population of medical clinicians and surgeons, and the lack of a replacement cohort.

Pursuant to the Age Discrimination in Employment Act (1967) there are no upper limit retirement age requirements for surgeons or most other professionals. The deficit between the growing demand for professional medical services and the limited population of training surgeons mandates that retention of general and specialty surgeons be comprehensive and efficacious in the coming decades. These actions are necessary not only to maintain a sufficient number of surgeons and to safeguard patients, but also important to protect the physician and surgeon population from malpractice litigation.

A program was recently initiated (The Aging Surgeon Program, Katlic, 2014) to evaluate surgeons' cognitive and physical functionality with objective measures to ensure an unbiased perspective. In spite of reported interest in the program, only one surgeon has attended since its inception (as of September 2016). In conversations with the program staff, the lack of participation may possibly be due to the time commitment and travel requirements (2 days of testing, not including travel to and from Baltimore). Lack of participation in the program might best be summarized in an opinion piece entitled "A Farewell to Surgery", Greenfield 1994, intuitively points out "the public can quite legitimately ask why it is that the older person must take an examination to drive but not to be an operating surgeon." Numerous physical and cognitive changes that naturally occur with aging are observed in older surgeons. In a brilliant and eloquent opinion piece by titled "A Farewell to Surgery" (Greenfield, 1994), parses through several physical and cognitive inevitabilities of aging and how each applies to the surgical profession (described in detail in Chapter 2).

Many psychological factors can alter mental and physical task performance, and this is especially true for individuals as they age. Late career professionals frequently witness their physical (Morgan et al, 1963) and cognitive (Powell, 1994) abilities in decline. Cognitive aging is separate from psychological and psychosocial aspects of aging such as implicit and explicit ageism. Explicit ageism is manifested intentionally when there is a conscious awareness by an institution or person with regards to the treatment of an older adult, whereas implicit ageism includes thoughts or actions manifested without conscious awareness (Levy & Banaji, 2002). Just as institutional racism exists in the current US society, an example of institutional ageism lies in organizations that lay off older workers before retirement or intimidate older workers to retire early. Implicit and explicit ageism, in combination with how much one might internalize it, can completely change the landscape of planning for retirement toward the end of one's career. Internalization of ageism and ageist beliefs can expedite the aging process and cause older adults to feel more handicapped or limited in their capabilities. Especially when faced with personal dilemmas (medical problems, spousal or familial needs, a recovering economy), planning for and implementing retirement or reduction of surgical hours may be intimidating. The embodiment of internalized ageism can be expressed as stereotype threat, which is the anxiety experienced in a situation where a person has the potential to confirm a negative stereotype (Hess et al, 2009). Stigma consciousness, another psychological factor that impairs performance, is the awareness and expectation of discrimination based on one's membership in a particular group (Pinel, 1999). Individuals who are high in stigma consciousness are more susceptible to the negative effects of stereotype threat on performance (Brown & Pinel, 2003).

Occupational self-efficacy is the confidence one has in their ability to perform their job correctly (Rigotti et al, 2008). Finally, age identity, or the self-identification with a cultural convention on how we should appear and act based on our age, can also alter how individuals react to certain tasks and social interactions (Westerhoff and Barrett, 2005). As Levy (2003) points out, the aging self-stereotype can alter cognitive and physical performance without an individual's awareness. Ageism expressed both internally and externally has the potential to limit older adults' capabilities (career and job security) and ultimately their independence (self care and living independently). This concept of surgeon self-identity is expressed frequently in the medical literature on retirement.

It would be a stark and startling change indeed to go from being a respected surgeon performing operations and potentially saving lives to a retirement that lacks all the measures of self-worth previously exercised every day. Surgeons and physicians strongly identify with their profession, possibly making them more susceptible to negative stereotype embodiment at the end of their careers. Rayburn (2015) expressed that "most physicians understand that they cannot "just retire". Some intellectual activity is needed to support their sense of self-esteem and worth." Dr. Ann Weinacker, vice-chair of medicine for quality implementation for Stanford Health Care, in Modern Healthcare magazine stated that being a physician "is not just what we do, it's who we are… The idea of someone saying, 'You can't do that anymore' is frightening". Understandably, retirement from any profession is jarring to those who do not prepare for it by assuming other responsibilities and roles in their personal lives. This is especially difficult for medical professionals for whom medicine is completely ingrained in their perception of self.

Heeding the predicted shortfall in the surgeon population, it is becoming increasingly important to develop ways to retain those professionals who are still capable of operating and to refine a system for determining set measures at which to revoke surgical privileges. Looking ahead, in order to efficiently train a new generation of surgeons for the aging population, the current paradigm of surgeon retirement is not sufficient. Specifically, retirement planning guidance is lacking in addition to psychological support services to aid surgeons and physicians through the difficult process of retirement.

Psychological aspects of aging may also influence a surgeon's actions in the operating room. Aging physicians and surgeons nearing retirement are commonly observed to have a lack of self-esteem, followed by a resistance to acknowledge mortality, and a resistance to change (Deckert, 1992). This diminished self-esteem associated with surgeons nearing retirement, combined with the controversy over whether aging surgeons continue to remain as efficacious in the operating room, could influence surgeons nearing retirement to unknowingly succumb to ageist stereotypes (Levy, 2009).

There is limited data on surgeon retirement age in the literature, with the most recent study available from 1995 (Jonasson and Kwakwa, 1996) citing an increase in retirement age. As the average age of retirement increases over all professions, many individuals looking to prolong their career will be faced with the same questions concerning the preservation of their cognitive and physical potentials. While the average age of surgeon retirement in the US has recently increased from 60.45 in 1984 to 62.97 in 1994 according to the outdated study (Jonasson and Kwakawa, 1996), this will not offset the need for surgical care due to the sharp increase in the aging population. More up to date figures were not available for the entire surgical workforce. Compared to the increase in the overall population, proportionally fewer surgeons enter the workforce each year. The next generation of surgeons in the United States will be diminished and less experienced compared to their more established counterparts (American College of Surgeons Health Policy Research Institute, 2010; Jonasson and Kwakwa, 1996). The rising aging population and reduction in surgeon numbers (due to retirement and the relatively high rate of burnout) may encourage existing middle-aged practitioners to stay in their practices longer (Dyrbye et al, 2014). Although the well-established declines associated with aging have been identified to limit older adults functionality, surgeon age, as a single variable, has not been shown to be a predictor of operative risk (Waljee et al, 2006). As surgeons age in their profession, the real and perceived changes in surgeon skill need to be assessed to determine the extent to which the aging process impacts performance and potentially dispel ageist myths. This emphasizes the need for a formal, proactive review process for older professionals and for surgeons specifically suggests on-going peer review in addition to an annual review process.

In line the medical field to setting objective performance thresholds, efforts must be taken to satisfy the needs to older workers (both in the medical field and other professions) in order to maximize workplace health and productivity. Efforts such as reducing older surgeon nights on call, mental health counseling on retirement transitions, and assistive devices in the OR are a few possibilities. Interventions that target and mitigate these physical and cognitive factors aim to limit the onset of potential age-related decline. A promising intervention for delaying onset of fatigue and fatigue-related nonpathologic tremor is the liquid cooling/warming garment (LCWG). While the efficacy of LCWGs is well documented, the mechanisms by which enhanced performance is related to peripheral cooling are not well understood. Limb tremor is exacerbated by fatigue and heat (Morrison et al, 2005; Lakie et al, 1994), and can encumber a surgeon during prolonged surgeries. Therapies implementing LCWGs have been documented to lower shell temperature, delay fatigue and reduce tremor under controlled settings (Lango et al, 2009; Lakie et al, 1994). These garments have shown to improve athletes' performance when used prior to and during physical activity (Dory et al, 2008; Thorson and Dancisak, 2007), and to improve a surgeon's perceived comfort and shell temperature during surgical procedures (Reinertsen et al, 2008; Harwell and Ferguson, 1983; Nag et al, 1998; Van Veelen et al, 2004).

This dissertation's translational approach has the potential to provide valuable data on the interactions between physical aging, muscle cooling, and the psychosocial constructs that might interfere with surgical skills. The relationships explored here could open new doors to medical professionals seeking to extend their careers. At the onset of this research, the main challenge that was anticipated appeared to be difficulty in recruitment. Several members of the dissertation committee cautioned that surgeon participation would be low. However, both a Chair in the Department of Surgery and Director of Surgical Simulation center were optimistic about recruitment potential. While time commitment and lack of monetary compensation may have hindered subject interest, these are rarely cited as deciding factors in surgeon skill studies. Since time and cost are not the primary factors in recruitment, this suggests a resistance to participate that is psychosocial in nature and potentially related to the age stigma and stereotype threat that so many older surgeons face toward the end of their career. Medical literature (Deckert et al, 1992; Katlic and Coleman, 2014) corroborates this suggestion but is sporadic (possibly indicating the difficulty in conducting research on aging surgeons), with a documented decline in self-esteem nearing retirement and an unwillingness to put down the scalpel. This study thus examines both a biomedical intervention to ameliorate potential physical constructs for older surgeons and unique psychosocial barriers to surgical careers maintaining in later life. By implementing a cooling garment paradigm to moderate fatigue, tremor, and the psychological susceptibility to such factors, we hope to achieve our ultimate ambition of extending surgeons' operative careers.

Aims

Aim 1: Determine the efficacy of muscle cooling on functional fatigue and physiologic tremor in late career professionals using a cooling garment.

Hypothesis: Short-term intermittent muscle cooling therapy increases time to functional fatigue and reduces amplitude of physiologic tremor compared to ambient temperature exposure.

Aim 2: Determine whether late career surgeons with pronounced physiologic tremor and fatigue embody ageist stereotypes as a consequence of perceived and real physical performance changes.

Hypothesis: Late career surgeons with a higher awareness of age stigma consequently fatigue more quickly and have more pronounced physiologic tremor.

Operational Definitions

– Please refer to this list for reference throughout the dissertation

1. Functional fatigue- the fatigue level at which one can no longer perform a certain task to their normal ability, based on the definition of fatigue given by Vollestad (1997) as “any reduction in the maximal capacity to generate force or power output”
2. Isokinetic functional fatigue- when a subject reaches less than 90% of their normal/baseline range of motion (ROM)
3. Isometric functional fatigue - when one reaches less than 70% of their maximum voluntary contraction

4. Physiologic tremor – nonpathologic, postural limb tremor. "Two distinct oscillations, mechanical-reflex and central-neurogenic" (Elble, 1996), both of which are "superimposed upon a background of irregular fluctuations in muscle force and limb displacement. The mechanical-reflex component is the larger of the two oscillations and its frequency is governed by the inertial and elastic properties of the body".

5. Stereotype threat- the anxiety experienced in a situation where a person has the potential to confirm a negative stereotype (Hess et al, 2009).

6. Stigma consciousness- the awareness and expectation of discrimination based on one's membership in a particular group (Pinel, 1999).

7. Occupational self-efficacy- the confidence one has in their ability to perform their job correctly (Rigotti et al, 2008).

8. Age identity- the self-identification with a cultural convention on how we should appear and act based on our age; can also alter how individuals react to certain tasks and social interactions (Westerhoff and Barrett, 2005).

9. Ageism- prejudice or discrimination on the basis of a person's age.

10. Cooling garment- garment designed to cool or warm designated muscle regions or thermogenic zones (location is dependent on the activity of the subject wearing the garment), consisting of small tubes running along the inside of the garment which are connected to a recirculating pump with a designated temperature

11. Intermittent muscle cooling- cooling to a temperature above noxious cold temperatures with a cooling garment. Intermittent because cooling should not last

for periods longer than 8-10 minutes and cooling (as opposed to icing) because icing induces vasoconstriction and pain

12. Maximum voluntary contraction (MVC)- the maximum force with which a subject can perform a certain exercise. Always less than the force that can potentially be generated by electrically stimulating the muscle to perform the same movement.

13. Personal identity formation (PIF)- individuation, or how one's identity is formed. While this applies to many genres (gender, profession, etc.), this document will use PIF to refer to the identity formation of a surgeon or medical professional

14. Cognitive – baseline psychological functioning and ability

15. Biomedical – of or relating to physical and physiologic properties of the human body or tools or therapies meant to assist humans

16. Psychosocial –of or relating to psychological constructs which can alter cognitive functioning; how our social environment can affect cognitive ability or perception

Chapter 2. Review of Literature

Issues Relevant to Aging Professionals

The Age Discrimination in Employment Act of 1967 prohibits age-related workplace discrimination against individuals 40 years or older. There are noted exceptions to this rule. Airline pilots for example are forced to retire from commercial flights at age 60. Early retirement of pilots continues but this practice has been disputed due to the dramatic increase in life expectancy since the 1970s when this measure was initiated (Birren and Fischer, 1995). It is unclear whether the age restriction in pilots was implemented due to a decrease in eyesight or the declines associated with physical aging overall. This dilemma speaks to the encompassing issue of older adults in the workforce, and how employers must react by either promoting or transferring them to less physically straining jobs that often end with the employee taking early retirement. Circumstances surrounding early retirement were recently discussed in the Gerontologist (van Dalen et al, 2015), reporting that European employers are also not developing strategies to promote active aging in the workforce. Global lack of foresight about an aging professional workforce results in employers resorting to exit strategies for potentially competent older workers. When there is a limited younger population to take the older workers place, either due to availability or insufficient expertise, only then is accommodation and investment in older workers seemingly a priority. Hudson (2015) also cites the widespread presence of age bias in the workforce and the need for governments to step in with incentives to encourage workforce development for older workers to emphasize their value. For the majority of working class adults, it is no longer realistic to live off of retirement savings if you expect to live 20 years past your retirement age. On a public policy level, the gap between life expectancy and pension age is growing and the current trend will "jeopardize the solvency of social welfare programs and inhibit economic growth" (Cummins et al, 2015). It will be vital to the baby boomer generation to encourage employers to find transitional roles for older employees, who often produce more quality work, instead of forcing retirement before they are ready.

Demographics in the Surgeon Workforce

The retirement of such a significant portion of the current workforce will result in several professions needing to prepare for replacement cohorts. The abating surgeon workforce in the United States highlights a need to train more surgeons and retain existing surgeons in the workforce longer to offset the rising US population's medical needs. According to a 2010 study, nearly 1/3 of practicing surgeons are 55 years or over (Walker et al, 2010); if these surgeons were all still in practice today, that would make 1/3 of practicing surgeons over 61 years of age. Additionally, evidence suggests that 17% of surgeons continue to operate past 70 years of age (Greenfield and Proctor, 1994). While age itself does not limit surgical performance, the peer review process "may not be useful, as there are political difficulties in approaching a senior surgeon, and most senior surgeons are not actually providing care with a surgeon of equal authority or experience" (Schenarts and Cemaj, 2016), pointing to inherent biases in the peer review system.

A dynamic model accommodating for the increasing population and projecting the future surgeon supply predicts an 18% decrease in overall surgeon number from 2009 to 2028. According to this dynamic stock and flow model none of the current or proposed initiatives to increase cohort numbers of graduate medical education will offset this decline (Fraher et al, 2013). The Annals of Surgery (Williams et al, 2009) specifically points to seven surgical specialties which will experience shortages in the coming 30 years, including otolaryngology, orthopedic surgery, thoracic surgery, obstetrics and gynecology, neurosurgery, urology, and general surgery. The model proposed by Fraher et al (2013) predicts maintenance of the surgeon population in colorectal, pediatric, neurological, and vascular surgical specialties. In 2009, if the maximum number of applicants to residency had been matched this would only cover 84.5% of the positions to be filled that year. The remainder of positions was filled by international medical graduates, which the United States has depended on over the past several decades to supplement the current surgeon population (Terhune et al, 2010).

In a report on the projected shortfall in medical professionals prepared by the Association of American Medical Colleges, Dall et al (2015) projected a surgeon shortage upwards of 25,000 by 2025 as illustrated in Figure 1. The overall number of general surgeons per 100,000 population in the United States has declined 25.91% in the last 25 years (as of 2005; Lynge et al, 2008). In order to meet the growing aging population's demand for medical services there should be a proportionate increase in the North American medical school graduates and resident positions in conjunction with an increased mentoring presence from the current surgical workforce. The Resident Physician Shortage Reduction Act of 2009 initially proposed a 15% increase in overall residency positions funded through Medicare and also specified preference for "... hospitals that submit applications for new primary care and general surgery residency positions..." (Etzioni et al, 2011). However, this act was not passed and was resubmitted in April of 2015 (S. 1148: 116th Congress) without the reference to surgery and little hope of passing out of committee. Congress wishes to pursue funding more surgical positions; however, the 2008 downturn in the US economy had limited the prioritization of growth in surgical and general residency programs. Political realities aside, if passed the bill would have added 15,000 resident slots from 2015-2019 (3,000 each year). Each year, half the allotted spaces would be reserved for areas with a projected shortage. Older surgeon mentorship of residents in the coming decade is also of pivotal importance. The significance of mentoring in a surgeon's career path is especially influential during the junior year of residency, and all current surgeons should be involved in mentoring the next generation (McCord et al, 2009).

The report also cited a decline in a physician's patient care hours per week from age 55 onward, with female physicians spending ~3.3 hours less per week on patient care activities than male peers. For physicians overall, females work an average of 5 hours less per week while under the age of 55, and two hours less per week over 55 than their male peers. This discrepancy is likely due to parenting and caregiver duties more frequently taken on by the female spouse. However, it is difficult to discern whether a reduction in patient care hours is necessarily due to a decline in overall work hours or devoting those hours to other work-related tasks such as education or administrative work.

An analysis of surgeon retirement in 1996 (Jonasson and Kwaka) cited an increase in the average age of surgeon retirement from 60.45 in 1984 to 62.97 in 1995. The most common factors for cause of retirement from 1984 to 1985 were disability (26%), leisure time (20%), and unfavorable changes in surgery (54%). By 1994-1995, the factors included in physicians reasons to retire were disability (14%), leisure time (20%), and unfavorable changes in surgery, which had jumped to 56%. While the United States has no mandatory retirement age, other countries require a minimum retirement age of 65 (Canada, Ireland, India) or even 55/60 (female/male; China, Russia) (Bhatt et al, 2016).

Assessment

Certain flagship hospitals in the US have developed evaluation procedures for older surgeons. As of 2012, Stanford University Medical Center has required physicians 75+ undergo mandatory accreditation every 2 years, which includes a physical examination, cognitive screening, and peer assessment of clinical performance, whereas the University of Virginia evaluates all physicians over 70 years of age (Bhatt et al, 2016).

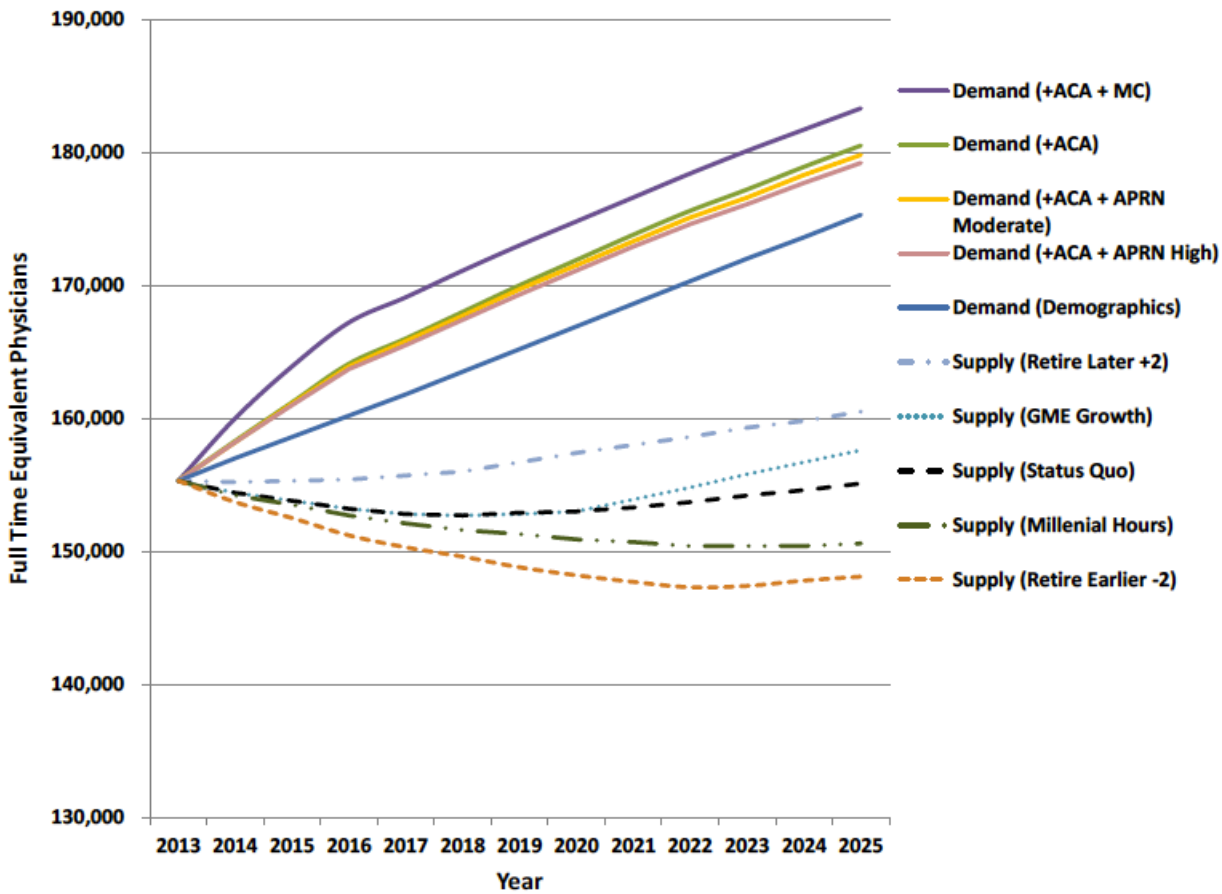

Figure 1. Projected Supply and Demand for Surgeons, 2013-2025 (Dall et al, 2015)

Lack of Standardized Procedure for Determining Surgeon Competency

There is no standard procedure for hospitals in the United States to determine whether a surgeon should have his operating privileges revoked. The 'standard', per say, is peer review and limited cognitive testing, which can enable bias on several levels. In some cases it is necessary to remove operating privileges due to diminished physical capability; however, the current recertification process used by many hospitals is limited to cognitive testing. Therefore, the responsibility falls to the surgeon and his peers to decide how to go about decreasing surgical access, assuming a medical malpractice suit hasn't already limited his access to the operating room. Regions of Canada have established inspection committees to evaluate surgeons aged 70 and above every two years (Grauer and

Campbell, 1983). A survey of surgeon opinion on the matter by Greenfield and Proctor (1999) states peer review as the main suggested path for revoking surgical privileges, in addition to onset of disability and in some cases surgeon age. More recent research has espoused the need for a universal procedure for removing operating privileges to ensure patient safety (Blasier, 2009; LA Bieliauskas et al, 2008; Bright and Krahn, 2010). Specifically, these studies request a more objective (thresholds for visual, motor, and cognitive decline) and unbiased (not conducted by colleagues) system for assessing surgical competence.

Malpractice litigation in the medical sector is a delicate subject that is well documented but not entirely understood. It was recently determined that 32% of all paid claims resulted from litigation from approximately 1% of physicians (Studdert et al, 2016). This study excluded physicians 65 years of age or older "because retirement was a rival explanation for absence of further paid claims"; however, the oldest cohort of 55-64 years was responsible for 35% of all claims (or 18,710 of 54,099 cases analyzed). While this study evaluated all physicians, certain surgical specialties accounted for high percentages of claims (internal medicine: 15%; obstetrics and gynecology: 13%; general surgery: 12%), whereas other surgical specialties accounted for very small percentages (plastic surgery and neurosurgery: 2% each). To give a frame of reference for how costly this can be to hospitals or those who run a private practice, only 3% of claims were paid whereas the rest were settled out of court, and the mean payment was $371,054 and the median was $204,750 (in 2014 dollars; no other monetary information was provided in the study). Limitations of surgeon aging also affect the hospitals and private practices that employ them. Medicolegal and economic challenges (Greenfield, 1994) both pose a threat to surgeons remaining in their practices. Any medical institution employing older surgeons faces a greater chance of malpractice litigation (as does the older surgeon), the likelihood of which increases as the surgeon ages. An ever-present factor, regardless of lawsuit likelihood, is the salary being allotted to the older surgeon, which takes up monetary resources that might otherwise be allocated for novice surgeons.

Psychosocial Contributions to Retirement

Retirement planning for surgeons.

Timing the end of a career in surgery is difficult. Surgeons' capabilities improve throughout their career as they acquire experience and adjust their surgical skills accordingly. This improvement continues up until a flexion point where their physical or cognitive regressions, however subtle, become influential factors in their ability to practice medicine. These limitations, possibly due to arthritis, reduced range of motion, or the loss of muscle mass associated with normal aging, become dangerous when surgeons prefer to ignore significant decrements and do nothing to counterbalance them (Charness, 1985). Low self-esteem, resistance to change and a reluctance to face mortality confound many surgeons' outlook on retirement (Deckert et al, 1992). Deckert and Belsky (1984) emphasize the importance of surgeons having something meaningful planned post retirement. Many surgeons do not have an adequate plan for phasing out their surgical responsibilities. This is especially relevant when a surgeon intends to sell their private practice, which may be devalued over the years if the surgeon's abilities have fallen below their prime or if medical malpractice lawsuits have been levied. In a broader study on adjustment to retirement, Dammam et al (2015) found that the ease of adjustment to life as a retired individual was varied across professions and relationship status (married, divorced and single, divorced and not single), but did not differ significantly between men and women. The study also mentions that the longer an individual is retired, the less likely they are to miss work and work colleagues. The implications for surgeons, who tend to reduce surgical hours and ultimately reduce office hours as well, could mean that their removal from the workforce is a particularly reluctant process by which surgeons themselves tend to draw out to ease the drastic changes in lifestyle and professional demands.

It has become increasingly evident that decreasing surgical workload and eventual retirement are complex subjects that medical professionals wish to address. Retirement has a major effect on a surgeon's self-image (Greenfield and Proctor, 1999), which emphasizes how intensely surgeons associate their profession with their identity. These documented observations point to an awareness of declining physical capabilities and how many surgeons find ways to sidestep the retirement issue.

Concerns Not Unique to Surgery

Surgeons are not the only professionals affected by the natural declines of aging. Many other professions require constant fine motor control and high levels of manual dexterity. A comparable profession to surgery in terms of manual dexterity demands, fine motor control requirements, and lifetime skill development would be professional musicianship. A musician's physical and auditory skills become more pronounced and refined over the majority of their professional career. While there is a well-documented decline in reduction of perceivable frequency range for hearing, this aspect of aging does not impede most musicians. In other measures including gap detection, speech in noise, and mistuned harmonic detection, musicians have exhibited less age-related decline (Zendel and Alain, 2011). Orchestras today are going through similar woes with respect to the issue of tenured, orchestral musician retirement. It has been suggested that hearing and dexterity in professional musicians is retained to a greater extent than nonmusicians (Brandfonbrener, 2003). If this postulation were confirmed, these qualities would be advantageous to older, tenured musicians looking to remain employed in their profession. However, if this suggestion were disproven it would give musical organizations an arguing point for the release of older, more experienced musicians who require a larger salary in favor of younger musicians. Musical production has been linked with increases in neural plasticity at all ages, which might serve as a protective effect against CNS degeneration (Cajal, 1999; Wan and Schlaug, 2010). While neural plasticity isn't correlated with muscle fatigue or tremor, increases or maintenance in neural plasticity would help an individual maintain their professional skills for career longevity. Additionally, since musicians are routinely required to memorize musical pieces throughout their career, the onset of cognitive decline might also influence their ability to memorize a piece. Could musicians have an enhanced memory capacity for music while dementia is observed in other areas? Neural plasticity might be the key to reducing cognitive effort resulting in greater central and peripheral fatigue. Drawing from this research, it would not be outlandish to suggest the presence an analogous system in place within the neural capacity in older surgeons. After decades of performing and perfecting a specific operation an older surgeon might still be more than proficient in the OR but might need assistance in other activities of daily living or self care.

Threat of Malpractice

A major factor that increases likelihood of career dissatisfaction is the threat of malpractice (Desphande and Desphande, 2011). This 2011 survey of surgeons (n=762) documented concern about the threat of a malpractice case being brought against them in the next 10 years. Several surgeons also expressed a day-to-day fear of malpractice litigation and went through preventative measures to prevent litigation including tests and consultations in addition to relying on technology. The Desphande paper also points to a negative correlation between quality patient time and threat of malpractice, and reminds the reader that adequate patient time is an ethical obligation for the physician. With many hospitals and medical organizations pressuring their physicians and nursing staff to see as many patients as possible, this might be partially responsible for the miscommunications that lead to malpractice litigations. Stress of malpractice litigation contributes to burnout, which is the single largest predictor of withdrawing from surgical practice (Shanafelt et al, 2010). Another survey study by Shanafelt et al (2012) looked into quality of life and preventative factors for burnout in surgeons (n=7) and found that "increasing weekly aerobic exercise and weight training to recommended levels, annual visits to their primary care provider, and age-appropriate preventative testing" were the most effective in preventing burnout. Surely, these three habits or interventions might improve any profession's degree of burnout and improve any adult's life.

While this survey had a very limited subject pool (n=7), many surveys and/or research studies on surgeons have a limited subject number either due to low participation rates or inherent complications of subject inclusion (due to medical privacy or HIPPA guidelines). However, this is the most up-to-date data available on surgeon burnout. However, Shanafelt also points to the tendency of surgeons and physicians being less likely to seek regular primary care check ups and a lack of adherence to suggested weight-training regimens.

Surgeon Burnout

Career satisfaction also contributes to burnout, and factors involved in career satisfaction vary among the different surgical specialties. Differences also exist between academic and private practice surgeons in similar specialties (Balch et al, 2011). Average workload (hours/week) for different surgical specialties are as follows: trauma (72.8), transplant, (68.8), vascular (61.1), cardiothoracic (65.3), urologic (55.5), general (58.8), colorectal (62.2), plastic (54.6), neurologic (61.5), otolaryngology/head and neck (54.3), surgical oncology (62.6), obstetrics/gynecology (57.0), orthopedic (51.1), and pediatric (65.8). Actual surgical workload (hours in the OR/week) were reported as follows: trauma (12.0), transplant, (16.5), vascular (20.0), cardiothoracic (24.9), urologic (12.3), general (18.1), colorectal (17.9), plastic (19.7), neurologic (18.0), otolaryngology/head and neck (13.3), surgical oncology (17.7), obstetrics/gynecology (13.0), orthopedic (13.2), and pediatric (19.4). Nights on call were reported as follows: trauma (2.3), transplant, (4.3), vascular (2.7), cardiothoracic (3.5), urologic (2.7), general (2.6), colorectal (2.7), plastic (2.8), neurologic (2.4), otolaryngology/head and neck (2.3), surgical oncology (2.1), obstetrics/gynecology (3.4), orthopedic (1.8), and pediatric (2.6).

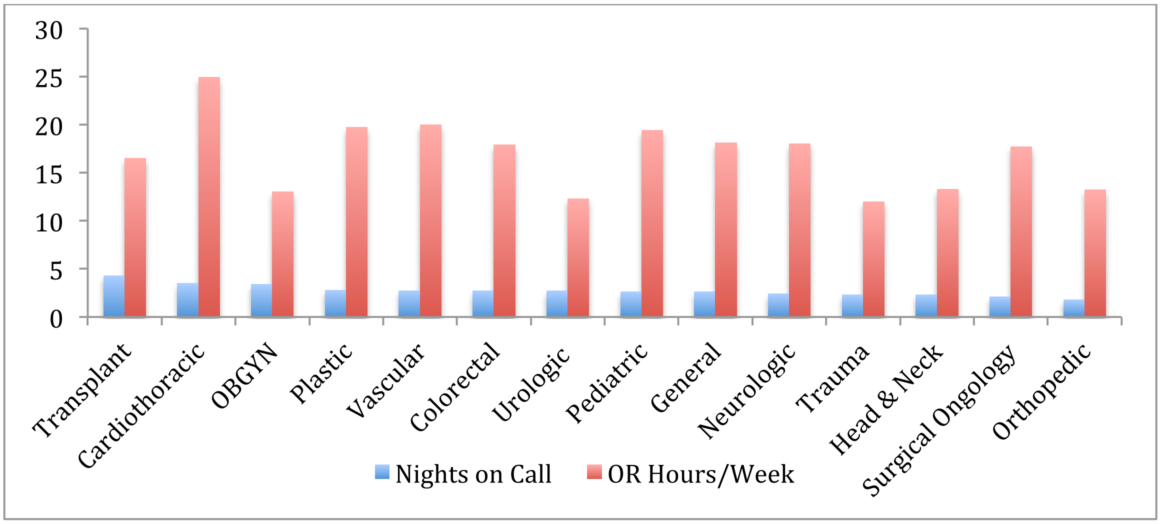

Figure 2. Nights on call and OR hours/week. Graph adapted from data provided in Balch et al (2011) on surgeon career parameters

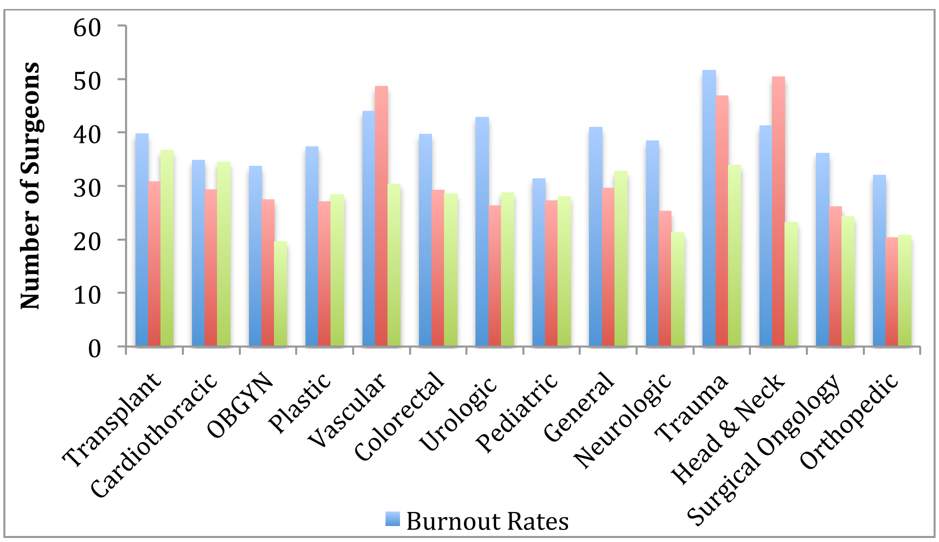

Figure 3. Burnout rates, Quality of life (QOL), and Depression Screening percentages per specialty. Graph adapted from data provided in Balch et al (2011) on surgeon career parameters

Physical Constraints of Aging

The process and mechanisms of natural, nonpathologic human aging can affect the body at every level. Sarcopenia becomes prevalent due to changes in muscle tissue, bones become weak and osteoporotic, and joint tissues commonly degrade and a decline in synovial fluid frequently results in the need for joint repair. Bilodeau et al (2001), describes neuromuscular changes with aging result in greater levels of voluntary activation failure (a subject's conscious decision to cease a muscular contraction) and peripheral failure (a subject's muscle giving out due to cramping or fatigue, which is involuntary). In a review entitled "The Aging Hand", Carmeli et al (2003) reference a 20-25% decrease in handgrip strength after age 60, the risk of osteoarthritis and rheumatoid arthritis (reported by 49.7% of adults 65 years and over; Cheng et al, 2010), and approximately a 25% reduction in motor axons of hand innervation. As for changes in range of motion, by age 70 there is an observed a 12% decline in wrist flexion, 41% decline in wrist extension, and 22% decline in ulnar deviation. Reaction time, as measured by fingertip force response showed that an older age group (average age of 78) had latency 3 times longer than the younger age group (average age of 30) (Cole and Rotella, 1998 and 2001). Lazarus et al (1997) found degraded central information processing capability and a deterioration of the cutaneous mechanoreceptors in older adults as compared to younger adults (65-74 years vs. 19 to 29 years), both of which are integral to most surgical specialties. Additionally, as handgrip strength is a common measure in aging research, Kubota et al (2012) showed a significant decline in controlled force exertion and maximal handgrip strength in elderly women (aged 72.9 $\pm$ 6.6 years) as compared to younger women aged 20.9 $\pm$ 1.9 years). As for differences between males and females, Carmeli states that the percentage difference in handgrip strength is similar in both sexes (2003).

"A Farewell to Surgery" (Greenfield, 1994) reviews the natural and probable physical and cognitive changes experienced by older surgeons and how these apply to the surgical field. Greenfield also takes time to emphasize that while these changes are typically more pronounced in normal adults compared to surgeons, surgeon data was on par with older adults of matched education and socioeconomic status. The author also describes how incidence of arthritis increases significantly (after 45 years), also reported are decreases in muscle elasticity limiting lower limb movement, contributing to shoulder muscle fatigue, strength declines (beginning in the forties and increasing every decade after that), and decreases in finger and arm strength (after 40), a 25% loss of overall strength (by 65 years). On a functional level, there is observed reduced motor unit recruitment, reduced nerve conduction velocity, reduced oxygen peak capacity, a reduction in the ability to diffuse muscle lactate (beginning at age 30 and increasing thereafter), pupil shrinkage, reduced tolerance of heat stress, etc. Also included is a decrease in maximal heart rate during exercise, which can increase perceived effort and decreases workload capacity. However, Greenfield cautions, performance, or "the ratio of allowed time for a specific task to the actual time taken for the job" is the limiting factor, not workload capacity. Quality of production for older workers is higher and typically yields fewer errors, but there is usually a point of diminishing returns (Shephard, 2000). Unfortunately, average performance ratings decline with age as well (Karnes et al, 1986).

The "loss of visual acuity, depth perception, and color discrimination" is also present in older surgeons (Greenfield and Proctor, 1999). The increase in cataracts and glaucoma and the onset of hearing loss are also mentioned as obvious limitations encountered with aging. Declines in manual dexterity and increased physical fatigue have been linked to the onset of arthritis and the increase in motor response time. As for the cause of these declines, physical fatigue and physiologic tremor are composed of both central and peripheral factors. Central fatigue and tremor originate in the CNS and can affect the entire body. Peripheral fatigue and tremor result from localized exhaustion of skeletal muscle and the significant reduction of metabolites required for physical performance. Both central and physical fatigue and tremor will be discussed in further detail later. Muscle fatigue and tremor can encumber those in professions where an advanced level of fine motor control and dexterity is required, such as using laparoscopic instruments to tie a surgical knot.

Fatigue and heavy workload were identified as major factors in the occurrence of surgeon error, though a definition of what constituted a heavy workload was not given (Gawande et al, 2003). Additionally, heavy workloads incite miscommunications between personnel providing care, which was also a significant contribution to surgeon error (Gawande et al, 2003). In order to reduce individual workload, the number of personnel is frequently increased which may increase error due to increased nodes of communication. Working too little also has negative consequences, since older surgeons reducing their surgical workload beyond normal hours (low procedure volume) was determined to be an important indicator of operative risk (Waljee et al, 2006). However, age alone was not a significant risk factor.

Hsu and Cooley (2003) found that surgeons are more likely to have pronounced tremor as a result of skeletal muscle fatigue. Ranganathan et al (2001) found a 30% reduction in whole handgrip strength ($P<0.001$) in older adults in addition to significant declines in individual finger strength, manual speed and muscular control. While aging does not affect thermoregulatory CNS response processes (Kenney and Munce, 2003), older adults do experience reduced "muscle strength, work capacity, sweating capacity, ability to transport heat from body core to skin, hydration levels, vascular reactivity, and lower cardiovascular stability" (Havenith, 2001). Under these contexts, limiting factors might reduce perceived comfort and mobility for older adults.

Cognitive aging

As discussed in the introduction, cognitive aging can be separated into performance on cognitive based tasks and the psychological perceptions of aging and how that affects ones daily life and capabilities. As for the psychological aspects of aging, we accumulate ageist stereotypes throughout our lifespan, which can influence cognitive and physical abilities in addition to medical events (Levy, 2003). Eventually we become old enough to embody these acquired stereotypes. With the average age of retirement increasing along with life expectancy, it would be beneficial to determine older adults physical and cognitive capacities of performing their professional duties at older ages.

When these physical and cognitive impediments are combined with new technology or unfamiliar procedures, consequences may result for the surgeon and more importantly the patient. With the rate at which technology advances, surgeons have to be constantly up to date on the most recent information and procedures available. This is encouraged in most hospitals with the "Morbidity and Mortality" and "Grand Rounds" type lectures where not only residents but also senior surgeons gain valuable information. Cognitive aptitude testing showed no significant differences between younger (aged 45-59; average 53.17 $\pm$ 4.26 years) and older (aged 60-86; average 67.61 $\pm$ 5.78 years) surgeons (Drag et al, 2010). Of the tasks completed, the visual learning and memory tasks proved most difficult for senior surgeons, while tasks requiring psychomotor speed were the least affected. When scores were cross-referenced with retirement decisions, there was a positive correlation between surgeons scoring well and having no imminent plans for retirement. Perceived cognitive decline, as investigated by Bieliauskas et al (2008), was not related to actual changes in cognitive ability, but did play a factor in the decision to plan for retirement. Lee et al (2009) suggests that surgeons' motivations to retire primarily based on self-perceived skill level and not age, (in addition to other factors such as family needs, financial issues, etc.) and stated that 60% of surgeons reported skill level (and not age) would steer their retirement decisions. *The Impaired Surgeon* (Hyde and Miscall, 1992) cites declines in motor coordination, reduction in short-term learning and memory capacity, altered judgment and the possible development of CNS degeneration (ex. mild cognitive impairment influencing working memory capacity) as influential factors in professional regression and eventual retirement.

Greenfield then explains that reduced performance is partially due to a reduced signal/noise ratio, not only between sensory organs and the brain but also within the brain, which can increase memory retrieval rates, putting a heavier emphasis on short-term memory workload. Reductions in memory recall also effected older physicians, as word-name blockage for surgeons over 65 years was 33% and short-term recall was 40%

compared to only 10-20% reported in physicians under 55 years for word blockage and 22% for short-term recall.

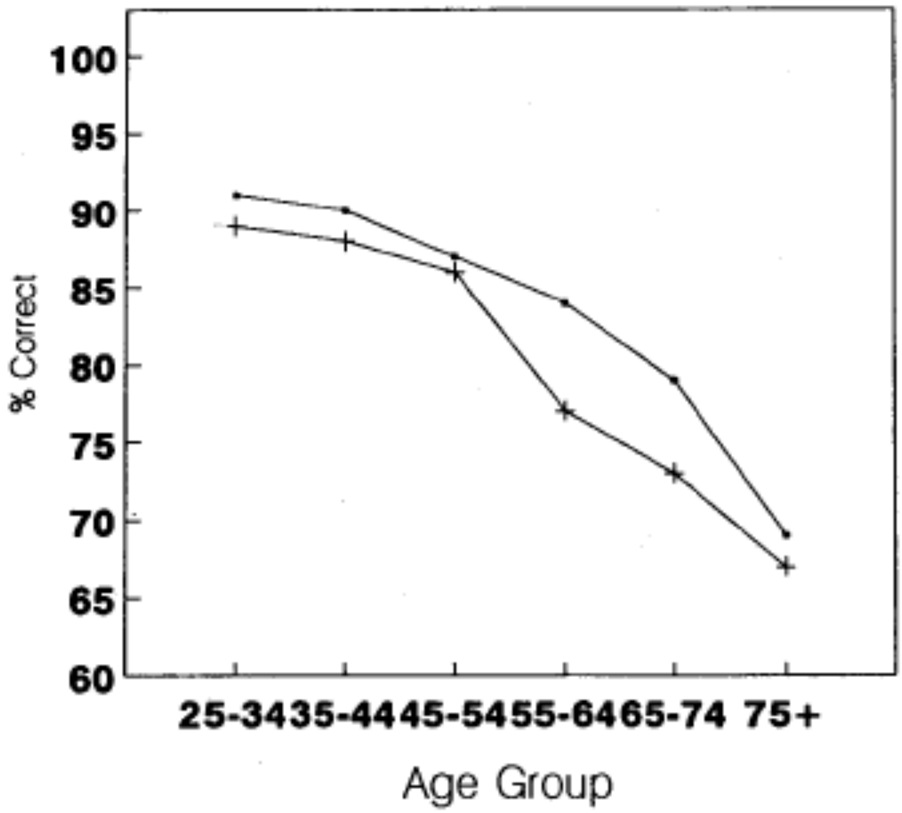

Figure 4. Comparison of total scores for physicians and normal control subjects by age group on neuropsychologic battery of tests. More rapid decline occurs after age 65 years. (From Powell DH, Whitla DK. Cognitive changes across the lifespan. In: Profiles in cognitive aging. Cambridge: Harvard Press)

A study of 1002 physicians (Powell and Whitla, 1994) showed a progressive reduction with increasing age in verbal memory, reasoning, and visuospatial ability whereas attention span remained the same for physicians and controls. A review on cognition of the aging physician (Eva, 2002) stresses the importance of not evaluating a physician based on their chronological age. This review emphasizes the dichotomy between using analytic skills versus non-analytic skills. As a surgeon ages and gains decades of experience and knowledge of the field, they tend to rely more on their developed experience, whereas younger surgeons do not have this to influence their decisions, forcing these younger surgeons to approach surgeries with a more analytic point of view. While this might enable younger surgeons to be more adept and have a higher proclivity toward new surgical technologies, it also might bias the development of their expertise and limit the breadth of knowledge in the less technologically advanced methods. Having a younger and older surgeon in the OR might help surgical teams approach each surgery with expertise and experience as well as an unbiased and more analytic point of view. A review of studies (Davis et al, 2006), mentioned earlier in the introduction, found that physicians are limited in their ability to self-assess surgical performance and emphasizes a more objective and external assessment process for surgical performance.

The Aging Surgeon Program at Sinai Hospital in Baltimore, headed by Dr. Mark Katlic is a two-day intensive course, which rigorously tests older surgeons' cognitive and physical capacities. Dr. Katlic notes that there are a projected 20,000 surgeons currently practicing over the age of 70 years. While mandatory professional practice evaluations are required in US hospitals every 6 months, these evaluations are not uniformly structured or implemented. The Aging Surgeon Program in Baltimore provides a comparatively objective measure of expected mental and physical surgical skills. In depth, the program includes physical and neurologic exams, physical/occupational therapy exercises (including reaction time, distance judgment, coordination, dynamic visual-spatial acuity), fine-motor control tests, and an eye exam. Neuropsychology testing evaluates attention, memory, executive functioning, emotional status, etc. The objective results of these assessments are made available to the individual and/or the person or institution that paid for the evaluation for them to make decisions about surgical privileges, continuing practice, and/or retirement.

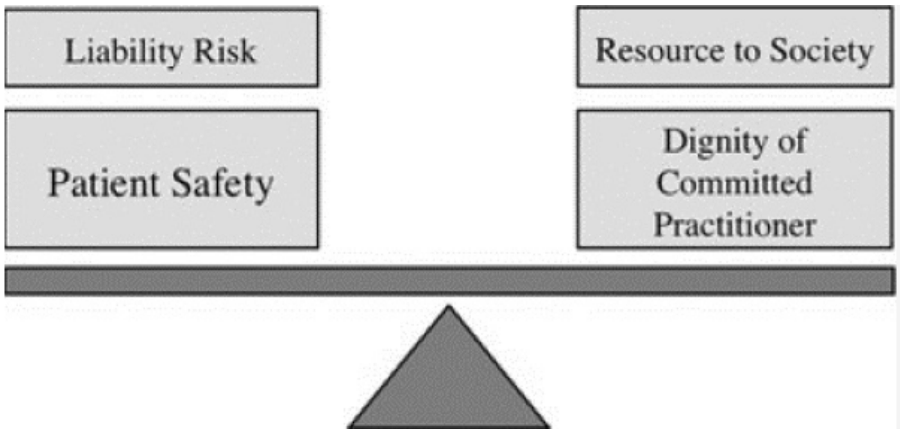

Figure 5. Retirement issues scale- Aging Surgeon Program

The lack of participation by surgeons in the Aging Surgeon Program has also been reflected in our own research with older surgeons. Whether the subject declined due to lack of monetary compensation or lack of their own free, time it was quite difficult to secure a surgeon's confirmation to participate, and even harder to actually have them show up at the facility on the agreed upon time and date. The request for quantitative research on older surgeons issues by multiple medical journals has gone essentially unanswered. While several survey studies have been conducted, there is a marked lack of physical and biometric data on surgeon aging and surgeon performance. Even getting surgeons to respond to surveys is difficult. There was an improved response rate in a review by VanGeest et al (2007) when using registered mail, with an increase of 16.5% compared to nonregistered mail. Tables 1 and 2 below from the review tabulate odds ratios and confidence intervals of several studies evaluating physician survey response.

As described, monetary incentives (Table 1) greatly improved response rates, especially compared to nonmonetary incentives (Table 2). However, these studies also showed large degrees of variability. Offering any money at all also creates a financial bias toward those who might be more or less financially secure. How much monetary compensation was also explored by Keating et al (2008), who found a significant difference ($P<.001$) in response rate (67.8% compared to 52.1%) when physicians were offered $50 instead of $20. In an investigation of successful recruitment strategies, McHenry et al (2015) found that "cultivating relationships with community-based organizations, face-to-face contact with potential study participants, and providing service (eg. blood pressure checks)" were the most rewarding in terms of subject participation. Of the 693 potentially eligible for the study, and an eventual participation subject pool of 276 and an attrition of 14.34%, this gives an eventual participation rate of 34.05%. While it is difficult to compare the surgeon survey participation studies to a randomized clinical trial recruitment from the general public, the data does emphasize the strategies that are considered most efficacious (maximizing accountability with registered mail, increasing personalizability with phone calls and face to face interactions, etc.).

Monetary Incentives	Intervention	OR	95% CI
Gunn & Rhodes (1981)	$25 vs. no incentive	1.59	0.98–2.59
	$50 vs. no incentive	2.46	1.47–4.12
Mizes et al. (1984)	$1 vs. no incentive	2.66	1.03–6.86
	$5 vs. no incentive	2.66	1.03–6.86
Berry & Kanouse (1987)	Prepayment vs. postpayment	1.83	1.50–2.23
Berk et al. (1993)	$10 vs. no incentive	2.01	1.15–3.50
Everett et al. (1997)	$1 vs. no incentive	2.07	1.46–2.93
Deehan et al. (1997)	£5 vs. no incentive	2.07	1.55–2.76
	£10 vs. no incentive	3.03	2.30–3.99
Easton et al. (1997)	$1 vs. booklet	2.12	1.47–3.04
Donaldson et al. (1999)	$5 vs. no incentive	1.62	1.09–2.41
Moore & An (2001)	$10 vs. no incentive	1.98	1.37–2.87
Kasprzyk et al. (2001)	$15 vs. no incentive	6.38	3.36–12.12
	$25 vs. no incentive	6.06	3.20–11.47
Leung et al. (2002)	HKD$10	1.07	0.52–2.23
	HKD$20	2.09	1.13–3.88
	HKD$40	2.52	1.38–4.58
Delveno et al. (2004)	Prepayment vs. postpayment	1.81	1.42–2.30
Leung et al. (2004)	Prepayment vs. postpayment	1.81	1.32–2.48
Burt & Woodwell (2005)	$50 vs. no incentive	1.00	0.74–1.35
Robertson et al. (2005)	AU$2 lottery	1.48	1.00–2.18

Table 1. Monetary incentives review provided in Keating et al (2008)

Nonmonetary Incentives	Intervention	OR	95% CI
Sallis et al. (1984)			
2nd mailing	Pencil	2.30	0.81–6.54
3rd mailing	Pencil	0.91	0.41–2.03
Mullen et al. (1987)	Sticker	1.11	0.75–1.66
Bonito et al. (1997)	Risk disk	1.05	0.80–1.36
Ward et al. (1998)	Pen	0.96	0.72–1.28
Baron et al. (2001)	Prize draw	1.29	1.00–1.67
Clark et al. (2001a)	Pen	0.96	0.77–1.19
Halpern et al. (2002)	Candy	0.62	0.49–0.79
Moses & Clark (2004)	Prize draw	1.09	0.88–1.35
Burt & Woodwell (2005)	Candy	0.79	0.58–1.06

Note: OR = odds ratio; CI = confidence interval. Table includes only those studies where sufficient information was available to calculate odds ratio measures of effect size.

Table 2. Non-monetary incentives review provided in Keating et al (2008)

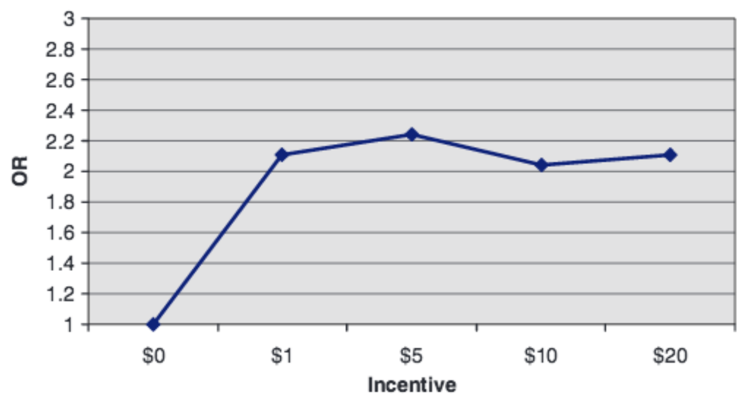

Figure 6. Average Effect Size (OR) by Monetary Incentive Level

Limited longitudinal and baseline data

While certain declines and changes with aging are frequently discussed in the literature, little attention has been paid to baseline measures for many aspects of surgical capacity. While there are certain proficiency thresholds one must reach during a surgical residency, documentation after completing residency and eventual decline of skills has not been investigated. It would be greatly beneficial to have a body of longitudinal data to determine how physical changes occur over the surgeon's career lifespan. Numerous studies have been conducted on resident skill acquisition for laparoscopic tasks to determine the best methods for efficient acquisition and retention of surgical skills. It has been determined that laparoscopic simulator training improves performance in surgical residents (Stefanidis et al, 2006) and that virtual reality and video training simulators enhance surgical proficiency even though all skills are not retained (Stefanidis et al, 2005). The inadequate amount of longitudinal data also applies to other highly skilled professions, including athletes, musicians and performing artists.

Human thermal regulation

Systems approach

Thermal regulation has been studied in both humans and other mammals for centuries. Ample longitudinal and cross sectional data has been collected, allowing researchers to build thermoregulatory models and theories for thermal comfort and control. Mammals have adapted to and are able to maintain their core body temperature. Various physiologic systems and adaptive methods of heat gain and heat loss help us to regulate this equilibrium of approximately 37 degrees Celsius (98.6 degrees Fahrenheit). A basic version of the heat balance equation is (Parsons, 2003):

$$M - W = E + R + C + K + S$$

Where M is the metabolic rate of the body, W is mechanical work, K is conduction, C is convection, R is radiation, S is heat storage, and E is evaporation. When the rate of heat storage is zero (heat balance), the equation can be arranged as such:

$$M - W - E - R - C - K = 0$$

The unit of measurement for this equation is energy gain or energy loss (Joules) per second (Joules/second = Watts) per square meter (surface area; to account for persons of different size). When one accounts for the rates of heat loss for each of these variables the equation can become much more complex. The temperature and thermal properties of blood, muscle, fat, and bone are each influential in a body's ability to regulate temperature and thus must be considered during design of a liquid cooling/warming garment. For some explanation, according to this equation a human with a larger surface area would need to produce more energy to maintain the same body temperature. Clothing adds another layer of insulation, which can be factored in as well.

The block diagram below (Parsons, 2003) illustrates the major and minor pathways of the thermoregulatory system. The brain relies on the warm and cold dermal receptors to monitor temperature and if a higher or lower set point is reached, a thermoregulatory response, such as vasoconstriction/shivering or vasodilation/sweating, is initiated. This allows for the body to effectively maintain the proper temperature for organ function.

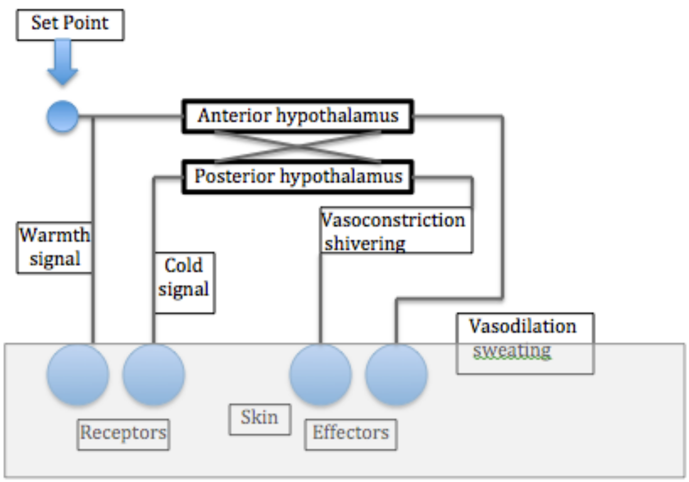

Figure 7. Thermoregulation paradigm from Parsons (*Human Thermal Environments*, 2nd edition, 2003)

The body's objective during vasodilation is to expedite heat loss, which occurs through warmer blood being nearing to the surface of the skin, promoting heat dissipation. The increase in conduction of heat from the blood to the skin then radiates from the skin into the air, dissipating body heat. Vasoconstriction results in a reduction of blood flow to the skin's surface (and therefore reduces thermal conduction and subsequent radiation), allowing for only the blood needed to deliver oxygen to peripheral tissues to pass. During design of a liquid cooling/warming garment, it is important to account for thermal regions of the body that are known to dissipate heat quickest, typically referred to as thermogenic zones, in addition to knowing areas to avoid due to their relative lack of blood flow.

The human body's homeostatic mechanisms' priority is to maintain core temperature. Shell temperature, or skin temperature, is regulated to a lesser degree, and can vary widely depending on the environment or activity of the human. Ears dissipate heat quickly and have a relatively low core temperature, whereas the mouth and inner ear typically have temperatures similar to core temperature, which is why this is where temperature is measured in the case of a fever. Circadian rhythms help humans (and animals) regulate core and skin temperatures and these patterns have been documented as far back as 1736 (DeGorter, 1736). Normal core temperature variation (with a typical wake/sleep cycle of being awake 7 am – 11 pm) goes from 36.5°C approximately 3 hours before waking, then rises to 37.2 °C at 9 am, and continues to rise slowly until reaching 37.4 °C around 2 pm, after which temperature slowly falls back to the starting point (Aschoff et al, 1967). These normal boundaries or variations in core temperature variation is termed normothermia and is highly variation between subjects but also for an individual throughout different seasons or stress levels. Temperatures greater than 42 °C can be damaging to both cellular and organ function (Lim et al, 2008). Skin temperature can be highly variable depending on where temperature is measured on the body and the ambient or environmental temperature.

Thermoregulation and fatigue

The effect of temperature on local muscle fatigue was reviewed in a meta-analysis by Quod et al (2006), which cited numerous studies showing benefits of precooling the body prior to endurance exercise in the heat. However, the review reserves recommending cooling therapy to athletic professionals due to the unknown mechanisms that result in an extension in time to fatigue. In another review Marino (2002) specified that whole body precooling benefits are limited to endurance exercises lasting up to 30-40 minutes, with no significant benefit observed for intermittent or short/high intensity exercises where the body temperature rises rapidly. However, Thorson and Dancisak (2007) demonstrated that collegiate athletes were able to maintain extended force production after isolated, intermittent short-term muscle cooling. An influential study by Grahn et al (2005) showed that heat extraction from palmar, glabrous skin resulted in a significant increase in exercise endurance at all workloads tested. Lango et al (2009) were able to improve surgeon comfort and fatigue levels through the use of a cooling vest. The discrepancies in the literature not only point to the varying methodology present in the research (intermittent vs. constant; isolated vs. whole body; type of exercise performed) but also to our limited and elementary understanding of the potential muscle cooling has to offer.

Molecular approach

Peripheral thermoreceptors are thermally receptive sensory neurons that perceive innocuous temperatures in cutaneous tissue. Cold thermoreceptors are close to the skin, spaced 5-10 mm apart, have a maximum firing frequency at 27° C, are both myelinated (Aδ-fibers, faster conduction velocity) and unmyelinated (C-fibers, slower conduction velocities), and are sensitive to proximal cold. Warm thermoreceptors (unmyelinated C-fibers) are located deeper within the skin and placed 10-15 mm apart with a maximum firing frequency at 45° C. These receptors are located within transient receptor potential (TRP) channels.

Thermosensation is facilitated by the transient receptor potential (TRP) family of cation channels in the plasma membrane and is the primary route of thermal stimuli. Some, but not all TRP channels are involved in thermosensation (Patapoutian, 2005). These channels mediate sensations of cool, cold, warm, hot, pain and pressure and can be found in several different cell types (McKemy et al, 2002). Certain chemical compounds including menthol and capsaicin also activate these channels. Various TRP channels are activated at specific temperature ranges, as illustrated in the figured below (reproduced from Romanovsky, 2007 and adapted from Patapoutian et al, 2005).

Of particular relevance is heat activated TRPV4 (transient receptor potential vanilloid 4), which is activated from 27-34° C and influences our body's thermoregulatory response. Upon activation during repeated tetanic stimuli in mice, TRPV1 and TRPV4 were shown to regulate muscle fatigue via calcium signaling (Patapoutian et al, 2005). These two ion channels (TRPV1 and TRPV4) also contribute to delayed onset muscle soreness (DOMS). While the relationship between TRPV1 and TRPV4 and DOMS is not completely understood, Ota et al (2013) suggest that TRPV1 contributes to DOMS downstream of the nerve growth factor and glial cell-line derived neurotropic factor, whereas TRPV4 is suggested to come into play only downstream of glial cell-line derived neurotropic factor. Cold activated TRPM8 (transient receptor potential, Subfamily M for melastatin), fluxes electrolytes (sodium and calcium) inward and is sensitive to both cold sensation and cold pain, including temperatures from 10-35° C. Awareness of these pathways allows researchers to isolate certain temperatures in order to target (or avoid) activation of channels associated with muscular fatigue. While TRP channels seem to play a role in metabolic syndrome and the associated cardiovascular risks from metabolic syndrome (Zhu et al, 2011), these channels' role in aging remains unclear.

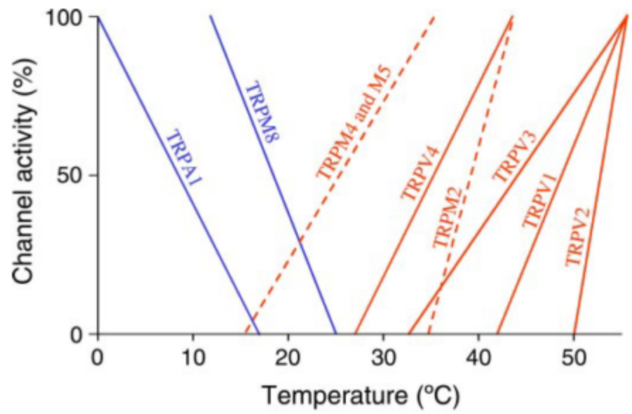

Figure 8. TRP ion channel temperature activation. Heat activated = red; Cold activated = blue (Patapoutian et al, 2005)

Located within the plasma membrane, NA,K-ATPase is an antiporter protein that pumps sodium (Na+) out and potassium (K+) in. While the NA,K-ATPase protein occurs in all animal cells in addition to the α1 isoform, the α2 isoform primarily occurs in skeletal muscle. Other isoforms of this protein include α3 and α4, and β1-β4 isoforms (Blanco, 2005). Until recently, the functional significance of the NA,K-ATPase protein isoforms was unknown. Radzyukevich et al (2013) found that the NA,K-ATPase α2 isoform also plays a tissue specific role in skeletal muscle fatigue by enabling these tissues to maintain contraction in mice. In an analysis of NA,K-ATPase pumps and their transport rates, Clausen (2013) found these pumps to be regulated by several factors including exercise, potassium deficiency, age, fasting, and inactivity. Furthermore, a recent study found a 25.5% reduction of the NA,K-ATPase protein in an older (69-81 years) subgroup of adults compared to a younger (55-68) subgroup (Perry et al, 2013).

These studies provide vital evidence of the fundamental mechanisms for increased rates of fatigue in aged mammals, and suggest the possibility of a stepwise decline in functionality for older adults.

Aging and human thermoregulation

Age related changes in thermoreception are somewhat limited. Quantity and density of thermoreceptors do not change with age, and the areas of the brain associated with thermal perception (neocortical primary sensory areas) also remain intact (Brody, 1992; Raz et al, 1992). Thermal perception and thermal sensitivity studies generally vary (not to mention between subject thermal sensitivity variability increases with age). Thermal comfort studies indicate a general reduction in thermal sensitivity possibly resulting from changes in the skin; this is especially observed in the lower extremities (Van Someren et al, 2002). With aging there is an overall decrease in the circadian cycle and decrease in temperature overall, possibly due to decreased sleep times and changes to the central pacemaker (Weinert, 2010). Temperature in older adults was documented by Gomolin et al (2005) to be significantly colder for three different age ranges (65-74, 75-84, ≥85; see Figure 9 below). This corroborates a stepwise and progressive reduction in temperature, which perhaps reflects the reduction in metabolic processes as activity becomes increasingly abridged with age.

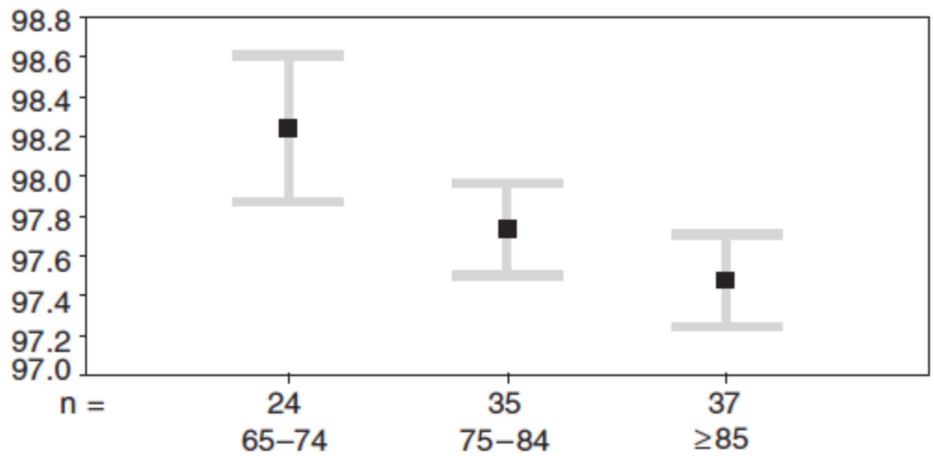

Figure 9. Average temperature range in older adults (Gomolin et al, 2005)

While there is some variation in females due to the menstrual cycle, circadian patterns are still observed. Hot flashes and flushing is commonly experienced by women who are pre-menopausal, peri-menopausal, or even post menopausal and can happen several times throughout the day and night (can disrupt sleep), and can last from minutes to hours. Kronenberg et al (1984) measured an average 3.9 °C rise in finger temperature (n=11 post menopausal women who frequently experienced hot flashes). Since reducing skin temperature has been shown to reduce the frequency and severity of hot flashes (Kronenberg and Banard, 1992), older female surgeons may stand to benefit most from the muscle cooling intervention.

Thermal regulation in the operating room

The typical variation in humans' circadian rhythms and how those variations might change with age has been well documented, even in the operating room environment. Standards for operating room temperature, as explained in Technical Fact Sheet ISO 7730 (2013), are described for consistency across hospitals and clinics for the temperature at which staff and patients should expect to experience. In the following equation, t_a refers to the air temperature and t_r is the mean radiant air temperature.

$$t_o = \frac{t_a + t_r}{2} \quad [°C],$$

Not only the operating room itself but the comfort levels of individual staff members is also of particular interest to the medical community. Wyon et al (1968) analyzed several aspects of surgical staff comfort, and the relative proportion of staff comfort is illustrated in the figure below (Curve 1: surgeons; Curve 2: surgical assistants and nurses; Curve 3: anesthetists).

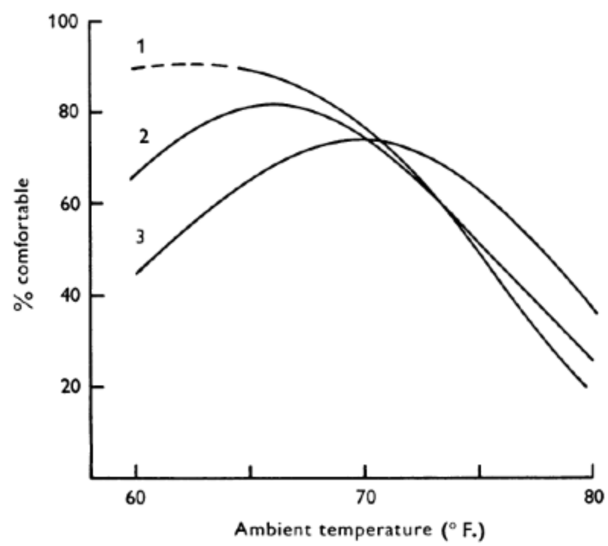

Figure 10. Comfort ranges of OR staff (Curve 1: surgeons; Curve 2: surgical assistants and nurses; Curve 3: anesthetists). (Wyon et al, 1968)

Bernard (1985) states that the commonly acceptable temperature for patients typically ranges from 22-27 °C (or 71.6-80.6 °F) with 50% relative humidity, and surgical staff comfort usually falls within the range of 19-20 °C (or 66.2-68 °F). However, any ambient temperature below 21 °C has the potential risk of patient hypothermia (which, by definition, is when the human body core temperature is below 36 °C). Additionally, for air quality (sterility) and temperature control, it is recommended that the air within the OR undergo 20-22 room changes per hour. While the Bernard article does not reference different types of surgeries, orthopedic surgeries are generally considered more physically draining than other types of minimally invasive surgeries (and thus the preferred surgeon temperature is lower).

In order to maintain patient temperature above a hypothermic state, several methods have been using including blankets, ‘space’ (aluminum) blankets, ventilated mattresses (Climator) which supply warm air to the patient compensating for heat loss through the surgical table), and warm fluids supplied to the patient through an IV. Patient safety is achieved through these compensatory mechanisms to ensure their temperature remains within safe boundaries, but other systems could be modified, such as cooling the surgeon without cooling the entire room, to facilitate a slightly warmer room temperature. Warmer room temperatures would not only be better for the patient, but for the OR staff as well, which could increase productivity and reduce communication errors which sometimes result in more serious medical mistakes. Another important aspect of hypothermia in surgical patients is that older patients (>60 years; n=198; ages ranged from 17 to 87 with an average 50 $\pm$ 1.3 years) were found to have significantly lower recovery room admission and discharge temperatures (see Figure 11) as compared to their younger counterparts (Vaughn et al, 1981). Considering a large percentage of the population will soon be 65+, many of them needing surgeries, this is a relevant and influential study that supports hypothermia prevention in surgical patients. Bernard also warns against surgical lights emitting too much heat and causing heat stress to the surgical staff; however, most hospitals have converted to more energy efficient (and reduced heat emission) light sources by now. However, this might not be the case in other countries less technologically advanced.

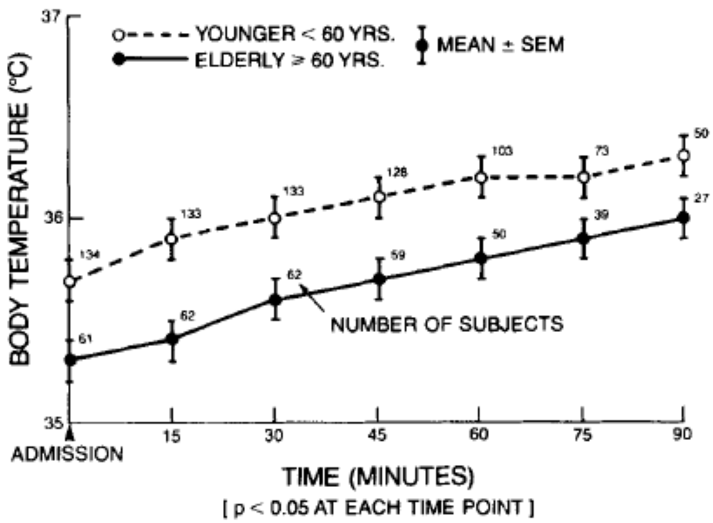

Figure 11. Young and old cohorts tympanic membrane temperatures at recovery room admission time and 15 minute intervals thereafter (Vaughn et al, 1981).

Melhado et al (2006) in an overview of staff thermal comfort defines the normal human temperature as between 36.1-37.2 °C (96.98-98.78 °F), the suitable patient temperature within the OR setting as between 24-26 °C (75.2-78.8 °F; below 21 °C or 69.8 °F is cited as hypothermic), and anything above 23°C (73.4 °F) as intolerable for the surgical staff. While there are no studies available on the relative productivity of various OR staff members at different temperatures (this would be unethical to manipulate), studies on other professions have shown that thermal discomfort decreases productivity (Fisk, 2000). Nurses and anesthesiologists commonly lament cold temperatures in the

OR, and the potential for decreased work productivity, especially with respect to miscommunication during surgery, could have serious consequences. Olesen and Bovenzi (1985) identify the following ideal temperatures for each OR member: anesthesiologists 23-24.5 °C, nurses 22-24.5°C, and surgeons 19°C. Considering the thermal comfort of all those in the OR, including staff and the patient undergoing surgery, might be a way to increase productivity and reduce communication error.

A more recent evaluation of surgeon and surgical staff thermal comfort conducted by Van Gaever et al (2014) emphasizes the physical impossibility of all surgical staff members being completely comfortable, as illustrated in the figure below (X values indicate temperature deviation from 19 °C, or 66.2 °F). While surgeon thermal comfort is usually a priority over other surgical staff, this is below the threshold for risk of hypothermia for the patient, who is especially subject to hypothermia due to reduced capability to thermoregulation under anesthesia. Reasons cited for surgeons requiring cooler OR temperatures include sterility issues, higher levels of clothing insulation (especially in the case of a lead apron) and heat expired from the surgical lights.

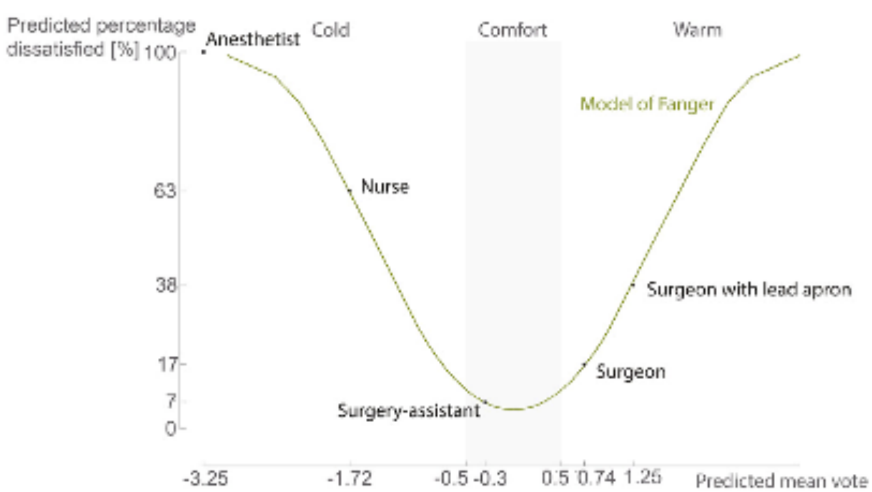

Figure 12. Comfort ranges of OR staff (Van Gaever et al, 2014)

Muscular fatigue – Overview

It is widely accepted that as one continues to get older there is an increase in chronic muscle fatigue. This applies to the spectrum of older professionals. Surgeons age and fatigue with the same predictability (and variability) as the general population. Reduction in muscle mass is one key aspect leading to chronic muscle fatigue. Zampieri et al (2014) found that a group of active, well-trained older men (average of 70 years) who exercised regularly, as compared to sedentary cohorts, senior sportsmen have "(a) greater maximal isometric force and function, (b) better preserved fiber morphology and ultrastructure of intracellular organelles involved in Ca^{2+} handling and ATP production, (c) preserved muscle fibers size resulting from fiber rescue by reinnervation, and (d) lowered expression of genes related to autophagy and reactive oxygen species detoxification." The encouraging prospect that age-related decay in muscle function and structure may be attenuated (but not altogether stopped) by regular exercise broadens our understanding of physical aging.

Molecular approach

Metabolite production is frequently cited as the reason for fatigue in anaerobic exercise. Accumulation of lactic acid, depletion of intracellular calcium availability, ammonium production, electrolyte depletion, and dehydration are all factors in the framework under which muscles become fatigued. Accumulation of lactate becomes pronounced during short-term high intensity exercise, which is more reliant on fast twitch muscle fibers (Lamb 1983). Fast twitch muscle fibers are more easily fatigued (Donaldson 1982) and have a greater capacity for lactate production due to their higher concentrations of glycolytic enzymes. Lactic acid accumulation is also responsible for the rise in pH during exercise (an indicator of fatigue) (Sahlin, 1982). However, Hermansen and Osnes (1972) were able to demonstrate that a finite lower limit for intramuscular pH exists (pH of 6.4 as opposed to a regular operating pH of 6.93), beyond which lactic acid production is halted and local muscular fatigue occurs. During intense physical activity, elevated temperatures accelerate the disassociation of hydrogen molecules in acid, increasing pH levels further. Intracellular calcium availability to contractile proteins is important to maintain cross-bridge formation and was found to correlate with force production (Richardson et al, 1980). Decreases in cross-bridge formation are attributed to decreased calcium-troponin binding and reduced myosin ATPase activation. Ammonium, produced by deamination of AMP during exercise, is associated with the onset of local muscle fatigue after short duration high intensity exercise. Ammonium also occurs in higher concentration in fast twitch fibers compared to slow twitch fibers, but plays a lesser role than lactic acid or calcium. While some research has attempted to address the indication that electrolyte (calcium, sodium, and potassium) and water depletion can lead to muscle fatigue, replacement of these ions does not alter onset of fatigue or slow fatigue (Karlsson 1971). Therefore, there is no isolated pathway of muscular fatigue, but there are additive aspects of peripheral muscle exhaustion and central activation failure that induce local fatigue.

An investigation of the relationship between fatigability and mitochondrial function in the quadriceps of older adult males (n=30; 78.5 $\pm$ 5 years) by Santanasto et al (2015) determined there was a lower capacity for oxidative phosphorylation (as measured with ATPmax and oxidative capacity) is positively correlated with higher fatigability (as measured by the perceived rate of exhaustion on the Borg Scale). This study is very important because it suggests the mitochondrial functional capacity in older adults skeletal muscle is compromised with aging.

On a molecular level, muscle fatigue is inversely related to cellular levels of ATP and creatine phosphatase, but these molecules are never fully depleted and therefore have not been considered a causative factor in muscle fatigue. However, intramuscular glycogen depletion has been shown as a contributing aspect in muscle fatigue. Both slow twitch and fast twitch muscle fibers are influential in muscle endurance, and muscle biopsies taken before, during, and after fatigue show a marked and progressive decline in glycogen levels specific to recruited muscle units (Bergstrom et al 1967; Gollnick et al 1973; Hermansen et al 1967; Karlsson 1971). Additionally, those measures that delay glycogen depletion also delay local muscle fatigue onset (Bergstrom et al, 1967). Increases in free fatty acids, oxygen availability, and increases in oxidative phosphorylation have not been shown as limiting factors in muscle performance.

With age, skeletal muscle mass, muscle strength and quality of muscle all decline after approximately 45 years. After 45 years there is an approximate decline of 5% per decade in static and dynamic muscle strength (Aoyagi and Shephard, 1992), and when combined with slower reaction speeds, these factors frequently result in detrimental falls (Larsson and Ramamurthy, 2000). There is also a shift in the type of muscle present in aged muscle biopsies, with younger biopsies having a greater proportion of Type II fibers and older biopsies having a larger percentage of Type I fibers (Aoyagi and Shepard, 1992). Strength decline has been directly associated with the decline in Type II fiber area (Larsson et al, 1979).

Skeletal muscle fatigue results from decreases in central nervous system activation and peripheral failure. While many studies point to central activation failure as being the sole cause, this observation is frequently a consequence of peripheral influences. In a hyperthermic state there is reduced voluntary force production for prolonged maximum voluntary contractions; this condition is also associated with decreases in central activation in motor unit activity, as observed by Nybo et al (2001). According to Bilodeua et al (2001), older subjects experienced significantly more voluntary activation failure than the younger subjects, which indicates the possibility of fatigue mechanisms changing with age. Taking this into account, older adults might stand to benefit more from an intervention aimed at reducing muscular fatigue levels. More testing is needed with subjects from multiple age groups (or a longitudinal study) to better understand how these aspects of fatigue are expressed over time.

Peripheral aspects of muscular fatigue involve overall metabolic factors such as the expenditure of the local energy supply and accumulation of metabolites within a particular motor unit or region of motor units within the muscle. While research has been vague as to which, if any, is a limiting factor among these processes, it is generally believed that a combination of reasons are responsible for the induction of muscle fatigue on a peripheral scale. Since there are no identified causal factors for induction of local muscular fatigue, one must address these processes as a complex system meant to facilitate the difficult tasks encountered during exercise and fatigue.

Systems Approach

In an analysis of central and peripheral contributions to muscle fatigue, Kent-Braun (1999) found that central fatigue is only responsible for approximately 20% of the reduction in MVC and peripheral fatigue, correlated with intramuscular pH was responsible for the remaining 80% of fatigue. Additionally, as MVC was observed to fall below 60% of its pre-exercise baseline value, there were negligible changes in inorganic Phosphate or deprotonated inorganic phosphate. The strong correlation between pH and onset of muscle fatigue also point to peripheral factors being the main cause of muscle fatigue, compared with central activation failure. However, it is suggested that a feedback loop exists between intramuscular metabolism and central motor drive during fatiguing exercise.

Proper posture is emphasized in medical workers, especially during surgical procedures, for fatigue and injury prevention. Berguer et al (1997) analyzed the differences between surgeon posture for laparoscopic and non-laparoscopic surgeries. During laparoscopic surgeries, experienced surgeons were found to exhibit more upright and static head and back positioning which is beneficial in prevention of fatigue during longer operations. Contrastingly, novice surgeons tended to flex their neck forward or lean over the table, leading to accelerated onset of fatigue.

Muscular fatigue in the operating room

Surgical Fatigue Syndrome (SFS), a term coined by Cuschieri et al (1994), describes the typical decline observed in surgical performance after 4 hours of surgery. Characteristics of SFS include mental exhaustion, increased irritability, decreased surgical judgment, and decreased dexterity. To combat this condition, the authors recommend rest periods (at least 10 minutes for every two hours) to reduce SFS severity. A more recent paper by Reyes, Tang, and Cuschieri (2006) discusses the frequency of overuse syndromes (tenosynovitis, repetitive strain injury, cumulative trauma disorder, acute carpal tunnel syndrome) incurred from minimal access surgeries and stresses the importance of improving the mechanical efficiency and ergonomics of laparoscopic instruments (specifically the instrument handle). Minimally invasive or minimal access surgeries (including laparoscopic surgeries) are the gold standard in terms of reducing infection risk to the patient and minimizing recovery time. This research cited increased effort prior to fatigue, as documented by EMG and motion analysis, as a major factor in the occurrence of these injuries. The anatomical issues cited mainly involve nerve compression as both the superficial terminal branch and the dorsal digital branches of the radial nerve and the palmar digital nerves may be compressed when manipulating the laparoscopic instrument due to the small diameter of the loops into which fingers must be inserted. Long-term manifestations (either from a prolonged surgery or several surgeries over time) of these actions may result in neuropraxia, axonometesis, or neurotmesis (nerve lesions). Preventative measures for SFS include a shared workload in the OR in addition to rests every 2 hours for at least 10 minutes.

As noted earlier, surgeon age is not considered a predictor of operative risk (Waljee et al, 2006). Testing on a set of cognitive tasks showed no significant differences between younger and older surgeons (Drag et al, 2010). Of the tasks completed, the visual learning and memory task proved most difficult for senior surgeons, while tasks requiring psychomotor speed were the least affected. When scores were cross-referenced with retirement decisions, there was a positive correlation between surgeons scoring well and having no imminent plans for retirement. Perceived cognitive decline, as investigated by Bieliauskas et al (2008), was not related to actual changes in cognitive ability, but did play a factor in the decision to plan for retirement. Lee et al (2009) suggests that surgeons' motivations to retire are not based on age but on skill level, (in addition to other factors such as family needs, financial issues, etc.). *The Impaired Surgeon* (Gordon and Miscall, 1992) cites declines in motor coordination, reduction in short-term learning and memory capacity, altered judgment and the possible development of CNS degeneration as influential factors in professional decline. This text emphasizes the need for a formal, proactive review process for older surgeons and suggests on-going peer review in addition to an annual review process.

Physical fatigue can alter a surgeon's ability to operate. Muscular fatigue studies use electromyography to evaluate fatigue and endurance levels in surgeons during the course of a surgical procedure. Luttman et al (1996) determined that the right trapezius was observed to fatigue more than the left trapezius, left or right mid deltoid, or the left erector spinae for surgeons in urology. Slack et al (2008) chose to record the mid deltoid and brachioradialis and found the latter to fatigue more rapidly in a variety of surgical procedures. Both studies used frequency analysis to determine changes in fatigue over time. Uhrich et al (2002) compared muscular fatigue levels in resident trainees' and attending surgeons' in the upper trapezius, sternocleidomastoid, middle trapezius, anterior deltoid, lower erector spinae, and hamstrings during mock laparoscopic tasks. While attending surgeons had significantly lower EMG amplitudes in the sternocleidomastoid, middle trapezius, and hamstrings than their resident counterparts, levels still exceeded the fatigue limits described by Jonsson (1978). This research was used to properly design the cooling garment for surgeons and appropriately develop a fatiguing protocol to evaluate tremor and fatigue.

While there are several different methods for measuring fatigue, using a measure of 'time to functional fatigue', as defined in the operational definitions, is a realistic and functional measure of the ability of a subject to perform a task. Electromyographic analysis, commonly used in fatigue studies to quantify fatigue, tracks the electrical activities of muscles or muscle groups. After transferring the raw signal into the frequency domain by performing a Fast Fourier Transform (FFT), the most commonly used quantities to characterize fatigue are mean and median frequency, and muscle fatigue is usually indicated by a downshift in both (Phinyomark et al, 2012). Mean frequency is defined as the "sum of product of the EMG power spectrum and the frequency divided by the total sum of the power spectrum", whereas median frequency is the "frequency at which the EMG power spectrum is divided into two regions with equal amplitude" (Phinyomark et al, 2012). Due to the shape of the EMG power spectrum, mean frequency is always slightly higher than median frequency from the same raw signal (Knaflitz et al, 1990). Possible reasons for the downshift in mean and median frequencies with fatigue include the modulation of motor unit firing rate (motor unit recruitment), the accumulation and slowing of conduction velocity, and signal synchronization (DeLuca, 1979; Hermens et al, 1984; and Viitasalo and Komi, 1977).

Sleep- Quality, quantity & performance

Job-related fatigue and sleep deprivation are important factors to consider in the operating room. These obstacles have been linked to an increased rate of technical error, cognitive error, and an increased time to completion in attending surgeons and resident trainees on laparoscopic simulation tasks and other cognitive tests. Gerdes et al (2008) cited an increased number of cognitive errors, a decline in psychomotor efficiency, and a decline in overall task performance in fatigued conditions (post-call compared to pre-call) for both attending surgeons and resident trainees. Studies (Kahol 2008 and Grantcharov 2001) conducted in a simulated surgical environment with residents and surgeons also found a decrease in cognitive and psychomotor skills post call compared to pre-call. While it is difficult to tease out whether the observed decrements are due to sleep deprivation or fatigue from hours of work, these factors are encountered together more frequently than not.

Human limb tremor

Tremor is considered involuntary rhythmic movement of any part of the human body and occurs in pathologic and nonpathologic forms throughout the human lifespan. Tremor can be divided by pathological/nonpathologic or by rest/action status. Rest tremor, mainly found in Parkinson's disease, occurs when a body part is supported against gravity. Action tremor is observed during any voluntary muscle action, and can be separated into postural, isometric, and kinetic tremors. Tremor is also classified by oscillation frequency. Common ranges include low (3 to 5 Hz), intermediate (5 to 8 Hz) or high (9 to 12 Hz). Physiologic tremor is a low amplitude tremor of the extremities constantly present due to our agonist and antagonist muscles acting to stabilize limb position. Physiologic hand tremor usually occurs at high frequency (8-12 Hz), low amplitude range (from less than 100 mm to 4 cm; Stiles, 1976) and is invisible to the naked eye. However, this form of tremor can be exacerbated during times of physical or mental stress, fear, anxiety, or fatigue. Our experiments look to determine the effect of cooling on physiologic tremor, which is considered a benign postural tremor (nonpathologic tremor which is not action or intention oriented).

Some evidence suggests bilateral and independent central components are responsible for the origin of physiologic tremor (Raethjen et al, 2002; Timmer et al, 1999), while the spinal stretch reflex loop (Constantinos et al 2006) and muscle spindle feedback (Erimake and Christakos 2008) play contributing roles. Physiologic tremor consists of a mechanical-reflex oscillation and an 8-12 Hz oscillation during regular muscle movements. Discrepancies in subtetanic motor unit signals and the cardiac systole are responsible for the mechanical-reflex oscillation (Elble, 1996). Tremor at the elbow has a lower frequency (3 to 5 Hz) than the wrist and hand tremor (8 to 12 Hz) because of the larger inertial properties of the forearm compared to the hand. Finger tremor frequency is even less damped and tremor at the metacarpophalangeal joint occurs from 17-30 Hz. Muscular contraction around the joint increases tremor whereas relaxation reduces tremor frequency. The 8-12 Hz oscillation is reliant on changes in motor unit activation patterns and not on the stretch reflex loop time or muscle twitch as previously believed (Elble 1996).

Aging and tremor

Elble (2003) showed that there were no significant changes in frequency or amplitude in the mechanical-reflex oscillation in young (20-42) versus old (70-92) healthy adults. In a study on physiologic tremor in resting and postural conditions in four age groups (young: 20-30 yrs, young-old: 60-69 yrs, old: 70-79 yrs, old-old: 80-94 yrs), Sturman et al (2005) found physiologic tremor amplitude at rest does not change significantly with age (Table 3). Normal physiologic tremor is defined as a low amplitude postural tremor with a central (modal) frequency from 8-12 Hz. No significant change was found in physiologic tremor frequency at rest with the exception of the old-old category, which showed a modal frequency decline.

Physiologic tremor is an ever-present obstacle to many surgical residents, especially in microsurgery (Harwell and Ferguson, 1983). Microsurgery residents are encouraged to avoid certain factors that exacerbate physiologic tremor. In a double-masked, placebo controlled study, Humayun et al (1997) baseline tremor deviated +15%, +31%, and −22% for placebo, caffeine, and propranolol groups, respectively. Options to reduce physiologic tremor include medication, meditation, the use of tremor-canceling devices, or altering limb temperature. Medicating with beta-blockers (propranolol 1 hour prior to surgery) significantly reduces tremor and anxiety levels in ophthalmic surgeons (Elman et al, 1998) as compared to placebo controls. While alcohol and benzodiazepines also reduce anxiety and tremor, they also result in a hindrance of higher central nervous system functionality. Significant increases of tremor were observed after upper-body strength or resistance and aerobic exercises in subjects (Hsu and Cooley, 2003). Figures 14 and 15, taken from Hsu & Cooley (2003) shows the increase above baseline tremor for each "upper body exercise" subject tested. As shown in the graph, immediately post exercise there was a large effect on tremor from baseline. Figure 3 compares the upper body exercise group to the aerobic exercise group, and while the differences between the groups are significant, both groups were observed to completely recover after 8 hours (shorter than the previously suggested 24 hours). Limb tremor amplitude increases with fatigue induced by exercise (Morrison et al, 2005) and heating (Lakie et al, 1994), whereas limb cooling and intermittent ischemia has shown to reduce tremor amplitude.

Therefore, it is best to reduce a surgeon's exposure to fatigue-induced tremor and could additionally reduce tremor through limb cooling.

Table 3. Physiologic Tremor Amplitude & Frequency, Sturman et al (2005)

Dependent Variable	Load, g	Young (20-30)	Young-Old (60-69)	Old (70-79)	Old-Old (80-94)	Essential Tremor	Parkinson's Disease
Amplitude, cm	0	0.04 ± 0.02	0.06 ± 0.04	0.06 ± 0.05	0.09 ± 0.08	4.67 ± 2.26	10.62 ± 8.97
	100	0.04 ± 0.02	0.06 ± 0.04	0.06 ± 0.06	0.09 ± 0.07	3.49 ± 2.23	5.89 ± 5.79
Frequency, Hz	0	8.33 ± 0.74	7.50 ± 1.10	7.45 ± 0.85	7.58 ± 0.50	6.07 ± 0.71	6.15 ± 1.04
	100	7.58 ± 1.10	7.11 ± 0.91	6.93 ± 0.69	7.16 ± 0.59	5.90 ± 0.72	6.20 ± 0.77

An older study (Marshall, 1961) looked at the mean frequency of physiologic tremor (no standard deviation given) and observed that the frequency declines after the age of 40 years from 10 cycles per second observed in 20-39 year olds to 6 cycles per second in those older than 60 years.

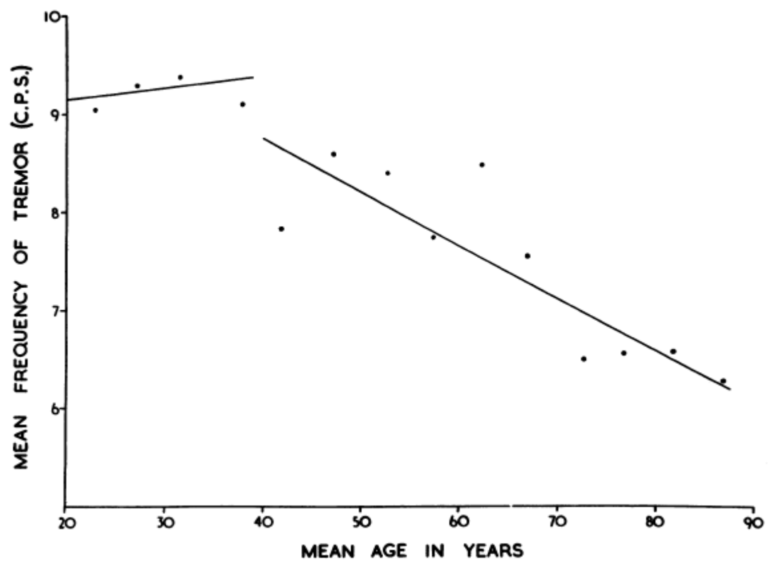

Figure 13. Mean frequency of tremor over a cross sectional data sample. Regression lines separated between 20-39 and 40-97 age groups. (Marshall, 1961).

Measurement of tremor

Electromyographic sensors (EMG), accelerometers, and velocity transducers are used to quantify tremor. Surface EMG analyzes the electrical activation of regions of motor units and data analysis can reveal when tremor becomes exacerbated. Accelerometers (single or multi-axial) are used to derive the first derivative (velocity) and the second derivative (displacement). Velocity transducers acquire an electrical signal that is correlated with a calibrated velocity; these transducers are more adept at measuring hand tremor since this is a low amplitude tremor and only one derivative is needed to determine displacement whereas accelerometers require two derivatives, which give a larger margin of error.

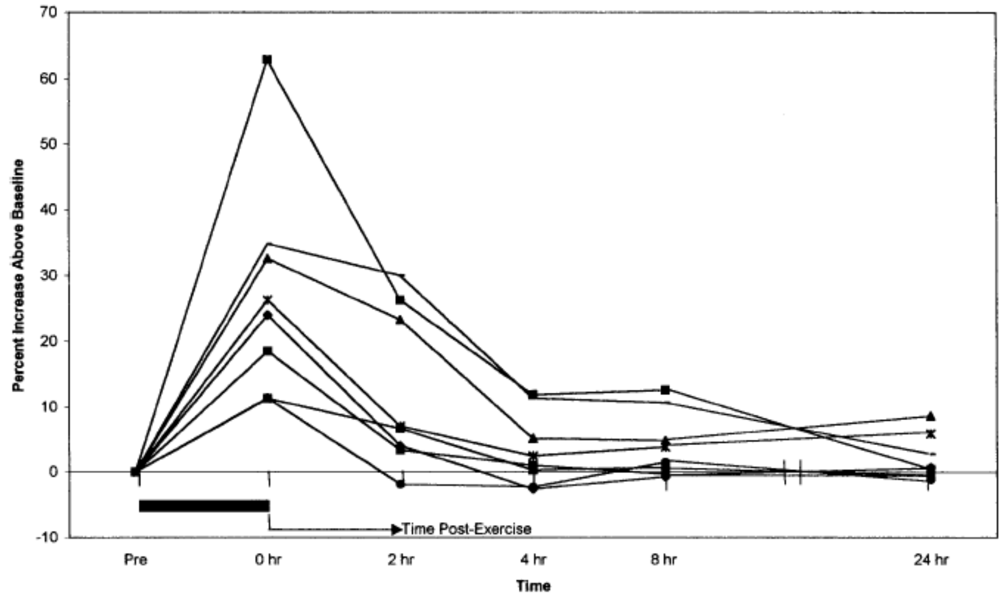

Figure 14. Surgeon percentage increase in physiologic tremor (above baseline) pre and post exercise (0-24 hours). Each line represents an individual surgeon's data, Hsu and Cooley (2003).

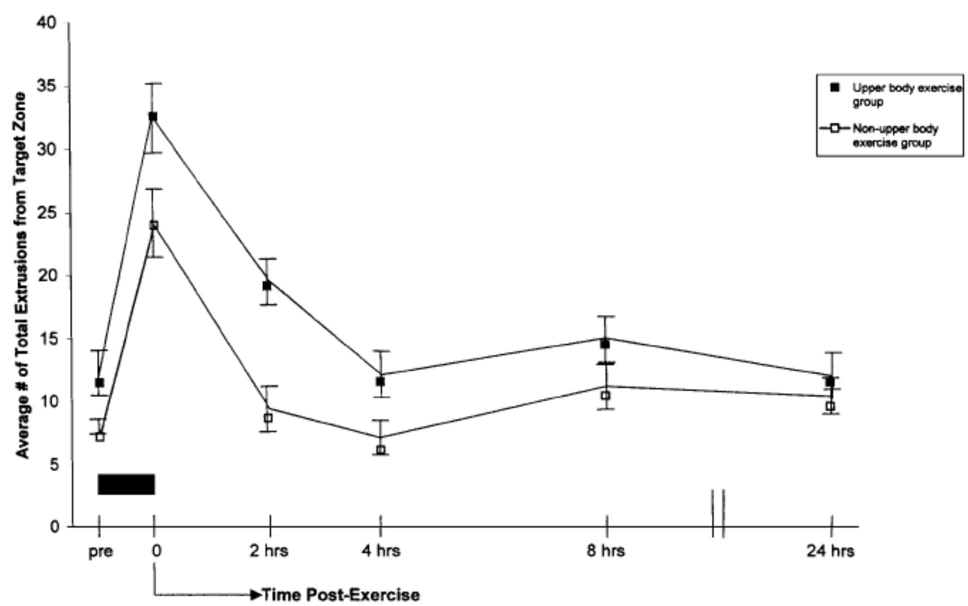

Figure 15. Average number of extrusions from target zone pre and post exercise (0-24 hours), Hsu and Cooley (2003).

Tremor levels did not return to baseline for two hours after aerobic exercise and 4 hours for upper body strength training. However, this is a much shorter time period compared to the previously recommended refractory period of 24 hours preceding a microsurgical case. Caffeine has also been shown to increase physiologic tremor, a factor that must be considered by sleep-deprived surgeons who are also concerned about levels of tremor (Humayun et al, 1997).

These observations have discernible implications for improvements in surgery. However, it is unknown if reduced tremor and an extended time to fatigue would necessarily lead to a better surgical outcome. It would be unethical to randomize patients to sleep-deprived surgeons or surgeons that have been driven past the point of physical fatigue. Therefore, this research looks to analyze the efficacy of our intervention in a simulated setting so as to avoid any ethically or legally abject situations.

The physical aspect of instrumental musical production can be quite demanding, and strenuous physical activity frequently elicits minor levels of physiologic tremor. Musician tremor can significantly impact the instrumentalist's ability to play and may ultimately end or alter their career (Lederman, 2007). While musicians can suffer from several types of tremor, essential tremor is the most common and the most problematic (Lederman, 1999). The research presented in this dissertation targets physiologic tremor since this poses the greatest threat to late-career surgeons. A direct relationship between temperature and tremor has been documented in essential tremor and nonpathologic tremor patients (Lakie et al, 1994), and therapies involving short-term, local muscle cooling have been suggested as a possible tremolytic.

Several older professionals, both musicians and surgeons, have noted the development of certain compensation strategies that can be developed to help balance the muscular load. However, if you have to focus on a compensation strategy this could easily influence your ability to focus on other tasks (working memory capacity). In surgery this is especially important when learning a new method for a surgical procedure, or when using a new technology.

Psychological constructs – Aging

An analysis of immunity to stereotype threat in older adults found that negative stereotype threat resulted in lower performance scores regardless of personal investment in physical activity (Horton et al, 2010). Those expressed an invested attitude in their physical capabilities consistently walked faster, but subjects were not aware that their walking times were being recorded. Those expressively invested in their own memory abilities had slower walking time and lower values of grip strength. Additionally, overall scores on reaction time, recall performance, and grip strength were found to decline with age (Horton et al, 2010). Included below is a theoretical framework developed by Schmader et al (2008) illustrating the three processes by which negative stereotype threat results in suboptimal performance on cognitive, social, and sensorimotor tasks. An individual's suppression response to both the physiological stress response and the constant self-monitoring process all combine to consume vital mental resources, resulting in lower scores on various tasks.

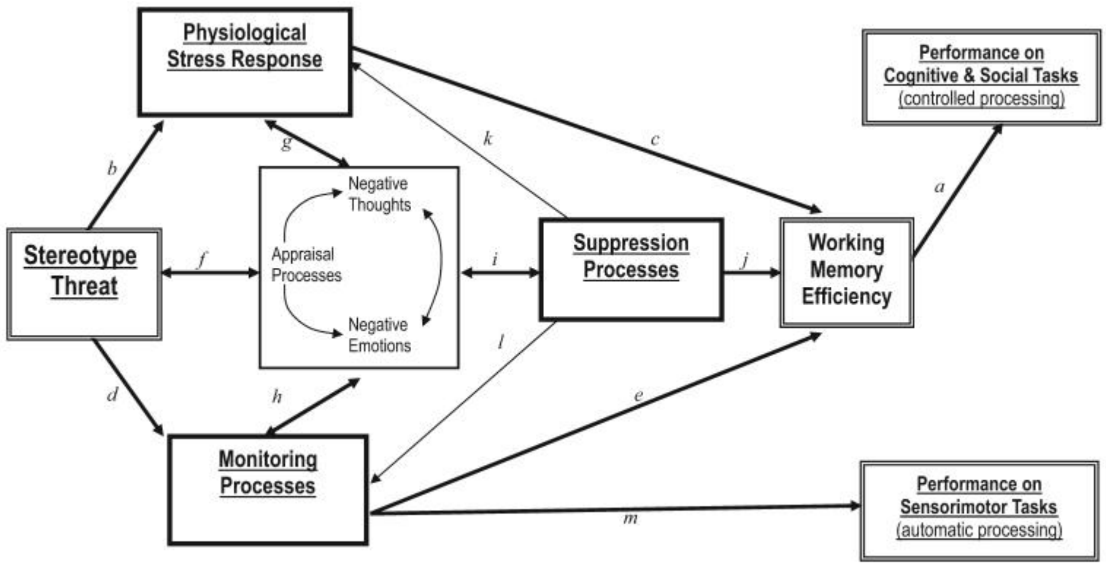

Figure 16. Theoretical framework of how stereotype threat contributes to declines in performance on cognitive, social, and sensorimotor tasks. Reproduced from Schmader et al (2008).

In line with this model, Levy (1996, 2000) has shown that negative stereotypes of older adults can impair their cognitive performance, and specifically cites anxiety as a factor in underperformance. Levy (2011) also points out that internalization of negative stereotypes over time can have a lasting effect on memory performance. Alternately, positive stereotypes may positively benefit an individual (Wills, 1981), ultimately improving performance through internalization and embodiment (Swift et al, 2013). Integrating this material, the attitude of the medical community should be adjusted to limit the negative effects of stereotype threat in sensitive populations (Kotter-grühn and Hess, 2012).

An individual's age identity dictates to that individual how they should act or perform in situations where age is a relevant factor. Research has shown that identifying with a younger age group correlates with higher values of life satisfaction and lower levels of negative affect (Westerhoff and Barrett, 2005). Therefore, it is beneficial for an individual to identify with a younger age cohort than an older cohort, which can have both social and physical implications. Levy has also shown that age identity can alter susceptibility to the effects of stereotype threat on performance (Levy, 2009). A 2006 study of 1470 Danish adults (aged 20-97) found that those over 25 and those over 40 on average feel 20% younger than their actual age; alternatively, adults younger than 25 have older subjective ages on average (Rubin and Berntsen, 2006). These beneficial associations might provide a protective effect against stereotype threat in older adults. These constructs are of particular importance for surgeons as this occupation is held in high esteem. Moreover, surgeons' perceptions of how efficacious their contribution is to the hospital or practice may incite heightened stigma consciousness and consequently limit physical or mental abilities. Therefore, it would be expected that those surgeons who are beginning to question their physical capabilities would have high levels of stigma consciousness. Since surgeons nearing retirement are documented to have lowered self-esteem (Deckert, 1992), stigma consciousness and stereotype threat research is essential in these sensitive populations to determine potential effects on cognitive and physical performance.

Ageism and ageist stereotypes may have far more negative consequences than originally expected. A longitudinal study of endorsement of age stereotypes (Emile et al, 2015) found that the greater the endorsement of ageist stereotypes the more negative ones subjective vitality, possibly due to ego depletion. Subjective vitality has been positively correlated with resilience and less susceptibility to illness (Benyamini et al, 2000) and higher mental health (Ryan and Frederick, 1997). Taking this concept a step further, another longitudinal study that tracked older adults for 10 years (Levy et al, 2015) found that negative stereotypes were associated with a significantly higher risk of hospitalization. In Levy's words "the stressful events did not increase the negativity of the age stereotypes over time; rather, the negativity of the age stereotypes predicted a stressful event." The importance of the directionality in this finding points to a potential causality that negative stereotypes influence the result of negative health outcomes, much like the fulfillment of stereotype threat situations presented in other studies. The likelihood of ageist stereotypes to influence health outcomes might be an embodiment of the 'stereotype threat spillover' experiments (Inzlicht and Kang, 2010) where experiencing stereotype threat can impact other decisions involving self-control (abandoning health eating habits, judgment and decision making, or even basic attentional control). In contrast, positive portrayals of aging result in positive perceptions of personal aging; however this was limited to realistic positive portrayals and was not observed with extremely positive, unrealistic expectations (Palmore, 2015).

To be a physician requires a transformation of the individual—one does not simply learn to be a physician, one becomes a physician.

— Abraham Fuks and colleagues, "The Foundation of Physicianship"

Pertaining to surgeon aging, much attention has been given to medical student over time embodying the physician title, and the reformation of self-identity as retirement approaches. Perhaps the complicated process of retirement from surgery has something to do with how one becomes a surgeon in the first place. As illustrated in the figure below (Cruess et al, 2015), the schematic of personal identity formation (PIF; a common term in medical education literature), of a medical student from student to resident to physician through socialization takes place over the course of medical school, residency, and intern years. The copings mechanisms used by medical students over the years to come to terms with the stress ingrained in the profession include a balance between emotional engagement and detachment, humor (both appropriate and inappropriate), and eventual cynicism (linked to burnout) for some. Cruess also mentions that there is no designated measure to follow a medical professional's PIF progression, whereas these tools are available for dentistry and even the military.

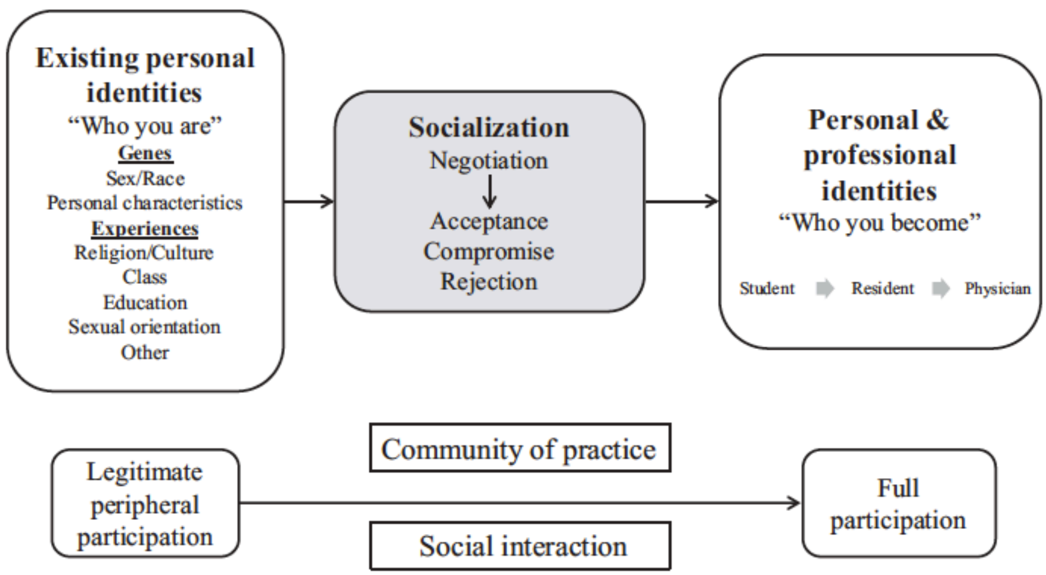

Figure 17. Figure from Cruess et al (2015)

"A schematic representation of professional identity formation, indicating that individuals enter the process of socialization with partially developed identities and emerge with both personal and professional identities (upper portion). The process of socialization in medicine results in an individual moving from legitimate peripheral participation in a community of practice to full participation, primarily through social interaction (lower portion)."- (Cruess et al, 2015)

On the other end of the spectrum, Onyura et al (2015) also mention the scarcity of psychosocial research on late-career physicians. Canadian academic physicians were surveyed on late career and retirement decisions (Onyura et al, 2015) from which four common themes of "centrality of occupational identity, experiences of identity threat, experiences of aging in a different system, and coping with late-career transitions" were identified. The psychosocial conflict between self-identity and retirement poses a real and pressing psychological threat to physicians' going through the retirement process, especially since study participants mentioned that organizational and system support for these late-career decisions was lacking.

Chapter 3: Materials & Methodology

Aim 1: Determine the efficacy of muscle cooling on functional fatigue and physiologic tremor in late career professionals using a cooling garment.

Musician Study

Stringed instrumentalists and keyboardists (n=30; average age 63$\pm$ 2.5 years; age range 51-83 years) were tested for muscular fatigue and physiologic tremor in two thermal conditions (thermal neutral 32°C/intervention 5°C) during separate sessions. While an effort was made to have an equal ratio of male: female test subjects, each subject served as their own control, eliminating issues comparing males to females (additionally: instruments are the same for males and females; there are no functional differences in playing methodology). After obtaining informed consent, Ag/AgCL surface electromyographic (EMG) sensors were place on the flexor and extensor (anterior and posterior) muscles of the dominant forearm. For stringed musicians, the dominant arm was considered the fret (left) arm. For pianists, the dominant arm was considered the right arm, as musical arrangements are typically more technically challenging for the right hand. All intervention and control trial sessions, began with a 10-minute thermal neutral acclimatization period during which subjects were allowed to become accustomed to wearing the cooling garment and normalize their skin temperature. The garment was made of stretch fabric with flexible tubing sewed onto the interior surface of the fabric.

Two standard commercial chillers (BESLAB RTE-110, Brinkmann Lauda RMS-6) regulated the temperature of the liquid in the garment.

All data was acquired at a sampling rate of 200 samples/second with the Biopac MP150 acquisition hardware and processed with the corresponding Acknowledge software (version 4.2). After 10 minutes of acclimatization, baseline tremor measures were acquired using a custom-built velocity transducer. Tremor was acquired by having the subject hold (with their dominant hand) a hemostat in which a flexible stylus was clamped onto the end of the instrument to allow for a positive interface with the transducer target arm (a phonograph needle with a contact surface area of ~1 mm^2) for 30 seconds. Subjects were allowed to rest only one finger of their dominant hand on the surface of the velocity transducer. Guidelines were affixed to the surface of the velocity transducer to guide participants in placing orienting their instrument in the same direction each trial. Only time on target was used for analysis (slips off of the needle were not counted). Tremor measures reported include the percentage change from baseline for tremor amplitude in the y (up and down) and z (back and forth) dimensions. Tremor amplitude is the maximum displacement for a particular dimension (y or z); these terms are interchangeable.

Figure 18. Velocity Transducer for tremor measurement. Orange tape guided hand/finger placement. Bimanual hemostat task (contact target/phonograph needle with stylus)

After baseline tremor and maximum voluntary contraction (MVC) force values were collected, subjects used a customized dynamometer setup to record finger force exerted by the 4th and 5th fingers. After placing the dominant forearm on a support and positioning the arm so that the wrist was proximal to the edge of the support so as to isolate the 4th and 5th metacarpophalangeal joint, subjects were asked to produce a MVC. Raw EMG data of the forearm flexors and extensors was also acquired during the flexion task. The time to less than 70% of their baseline MVC (>5 second duration) was determined and designated as the onset of functional fatigue.

After a subject reached functional fatigue, there was a 10-minute resting period (simulated intermission) during which liquid was run through the tubing of the cooling garment. The muscle cooling (Tc) condition consisted of a low thermal intervention (5°C, meant to quickly reduce skin temperature), and the control consisted of a thermal neutral condition (32°C). Presentation of trial order was planned using a randomized approach (coin flip) per subject. During the cooling protocol, muscle cooling was initiated (Tc) after functional fatigue for 8 minutes, then for the final 2 minutes of the resting period the suit was rewarmed to thermal neutral. For non-cooling trials there was 10 minutes of thermal neutral (32° C). Immediately after the rest period, recovery tremor was acquired in the same manner as baseline tremor. A total of three trials of fatigue, rest, and recovery tremor were completed per condition. The time to functional fatigue was recorded for each condition and trial.

Data reduction and analysis

Raw EMG signals were smoothed with a 50/60 Hz high pass notch filter to minimize or eliminate power line noise. The Fast Fourier Transform was performed to convert the data from the time domain to the frequency domain to calculate the mean and median frequencies of the last 5 seconds (onset of functional fatigue) of the third trial.

Tremor data was analyzed to detect the percentage of change from baseline in target displacement for each trial, and then noncooling values were compares from cooling values to determine if there was a significant difference between cooling and noncooling. Data was averaged over trials and statistical analysis was performed via a nonparametric sign test (SPSS, version 22.0) for tremor and fatigue. A post hoc power analyses was completed to verify adequate subject recruitment.

Surgeon Study

Surgeons were recruited for this study through contact with multiple clinics and hospitals in a midsize metropolitan region. Additional participants were recruited through word of mouth. After 18 months of active recruitment only individuals affiliated with the Tulane Medical Center and Tulane Medical School agreed to participate). Two cohorts were proposed for this study, the first cohort (Novice) included novice surgeons less than 35 years and the second cohort included experienced surgeons over 50 years of age. The Novice cohort included surgeons in their residency up until 5 years after completing their residency (maximum age of 35 years; average age 31.2 $\pm$ 2.1 years; age range 28-35). The second cohort (Experienced) included surgeons aged 50 and above (must have more than 10 years experience; average 60 years $\pm$10 years; age range 52-79). Power analyses for reduction of tremor with cooling were conducted using the approximate effect size of

0.5 (Cohen's d, 1988) calculated from the review by Tyler et al, (2013) to determine a sample size of 34 subjects per cohort (normal distribution; alpha = 0.5; power = 0.8). After 18 months of active advertising, recruitment was discontinued and the sample size for the two cohorts was reduced and case study analysis was performed.

After obtaining informed consent, Ag/AgCL surface electromyographic (EMG) sensors were place on posterior muscle bellies of the dominant forearm and deltoid. Regardless of intervention/control trial, each test session began with a 10-minute thermal neutral acclimatization period during which subjects were allowed to become accustomed to wearing the garment and normalize their skin temperature. During this time, subjects completed a brief survey (discussed in Aim 2) and questionnaire. The garment was comprised of stretchable fabric with plastic tubing sewed onto the interior surface of the fabric allowing direct contact with a participants skin. Two standard commercial chillers (BESLAB RTE-110 downtown) were used to regulate the temperature of the liquid in the garment.

All data was acquired at a sampling rate of 200 samples/second with the Biopac MP150 acquisition hardware and processed with the corresponding Acknowledge software (version 4.2). After 10 minutes of acclimatization, baseline tremor measures were acquired using the custom-built velocity transducer described in the musician study above. Tremor data was acquired by having the subject hold in each hand a hemostat with a flexible stylus clamped at the end of the instrument. Using both hands simultaneously, subjects were asked to depress with the stylus, the small target arms (phonograph needle, ~1 mm^2) of the velocity transducer for 30 seconds. Subjects were allowed to rest one finger of each hand on the surface of the velocity transducer to assist with maintaining contact with the target arms. Guidelines on the surface of the velocity transducer assisted in replicating hand position between trials. Only time on target was counted and slips off of the target arm were not counted. Tremor measures reported include the percentage change from baseline of tremor amplitude for the y (left to right) and z (back and forth) dimensions.

After baseline tremor, subjects were asked to complete a preliminary suturing activity for 3 minutes to practice on the device and to prepare the subjects for the fatiguing activity. The preliminary suturing activity was also implemented to help subjects learn the suture task and ask questions about specific instructions in order to reduce confusion and ensure that they were accustomed to the task. The intervention trials consisted of a low garment temperature (recirculating chiller at 5°C, meant to quickly reduce skin temperature) that cooled target muscles, and the control trials consisted of a thermal neutral (32°C) garment temperature. Presentation order for cooling/noncooling trials was established a priori using a randomized coin flip approach. The thermal condition (cool or thermal neutral) was initiated at the beginning of the fatiguing exercise that required each subject to complete a flexion/extension exercise with their arm extended out 90 ° anterior to the body holding a 5lb hand weight (Figure 19). Subjects were required to continue the flexion/extension exercise until they could no longer maintain within 10° of their full range of motion for either flexion or extension for three consecutive repetitions, as determined from pilot work. The thermal intervention was sustained for the entirety of the fatiguing exercise with 90 seconds of rewarming at thermal neutral at the beginning of the suturing task.

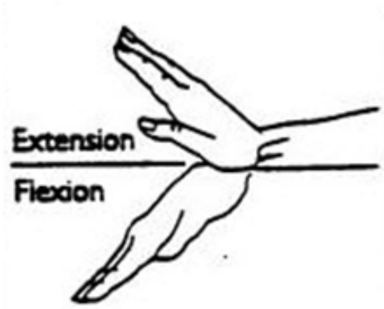

Figure 19. Subject required to flex and extend their wrist while holding a 5 lb hand weight (full range of motion; view from above)

Once subjects reached functional fatigue, subjects completed a timed suturing task. The suture task is comprised of five continuous running sutures, each of which must be closed with a square knot with four throws. This task was timed and subjects were informed that they have as long as they need to complete the task but they are being timed for efficiency and suture knot quality. After completion of the task, recovery tremor was recorded in the same manner as baseline tremor with the velocity transducer (Figure 18). During surgical operations efficiency is typically the goal, and as such there are often little to no rest periods. Especially in orthopedic surgeries, surgeons are often required to keep their own limbs stabilized while holding the necessary instruments to complete the operation for long periods of time. Therefore, no rest period was allowed for surgeons between fatiguing exercises in the protocol in order to mimic typical OR constraints. A total of three trials of fatigue task, suture task, and recovery tremor were completed per condition (cooling or noncooling).

Data analysis

EMG signals were smoothed through a 50/60 Hz high pass notch filter then analyzed to acquire the mean and median frequencies. Tremor data was analyzed to detect the percentage change in target displacement from baseline, and then the percentage difference from baseline (from trial to trial) was compared.

Aim 2: Determine whether late career surgeons are more susceptible to ageist stereotypes as a consequence of perceived and real physical performance changes.

Upon arrival to the test facility informed consent was obtained from each participant. While subjects completed the informed consent, for the study surgeons were informed of a brief survey to be taken before the first session and after the second session. The survey questions (Appendix I. Age Identity, Aging Measures of Stigma Consciousness, Occupational Self Efficacy Questionnaire) were coded and each question was cross-correlated with levels of surgeon fatigue and bi-axial tremor. The wording of these survey measures, validated in previous studies, have been slightly modified so as to make the measures applicable to age; however, care was taken to make sure the questions were not biased toward a particular age group. The basis of the survey originated from previously validated survey measures; however, some wording was changed to reflect age as opposed to gender.

Age identity was a single item measure, and therefore cannot calculate reliability for this measure, but was analyzed by how many years older or younger subjects' felt from their actual age. Reliability analyses for the Stigma Consciousness Questionnaire have not been conducted for ageism; the survey measure used in this research was based on research from Pinel (1999) on women on gender stigma consciousness (Cronbach's alpha= 0.77). Reliability analyses for the Occupational Self-Efficacy Questionnaire (Schyns and von Collani, 2002) resulted in a Cronbach's alpha of 0.86 (for the short version). Means and standard deviations for each scale were not provided in each research article, respectively. Both the Stigma Consciousness Questionnaire and the Occupational Self-Efficacy survey were administered with a 7-point Likert (1932) scale ranged from "Strongly Disagree" to "Strongly Agree", illustrated below.

	Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
Stereotypes about my age group have not affected me personally.	○	○	○	○	○	○	○

Figure 19. Qualtrics Survey Output Likert Scale example

Prior to beginning the first trial, subjects completed a Qualtrics survey that typically required less than 10 minutes to finish (online survey software services, www.qualtrics.com). From the beginning it was obvious that none of the surgeons would be inclined to complete the survey beforehand, so it was standardized for all initial surveys to be taken after informed consent during the thermal neutral acclimatization period. All follow up surveys were taken after the second trial prior to the surgeon leaving the testing facility. While this was not the ideal situation in terms of priming and the environment potentially having an influence in survey results, it was difficult enough securing a time for surgeons to come in for testing at all.

Prior to the first testing session (after informed consent was obtained), surgeons took the survey on the lab-provided laptop (MacBook Air) during the 10-minute acclimatization period. While each surgeon was encouraged to take the survey again after all data was collected, it was impossible to enforce this if the surgeon needed to leave due to time constraints. It was possible to opt out of the survey entirely.

If the subjects completed the second survey, it was taken on the same lab-provided laptop as before, after testing had been completed. Subjects were encouraged to take the survey as if they were taking it the first time ("try to answer as best you can as opposed to trying to repeat your initial answers"). A few instances occurred where the subject needed to rush to another appointment. While they were encouraged to complete the survey on their own time, this was impossible to enforce.

Data analysis

The subjects were asked to take the survey twice to determine if testing activities possibly influenced their levels of age stigma and occupational self-efficacy. However, since many subjects were unable to complete the survey twice, only the data from the first survey were analyzed. Correlational analyses were performed between each survey measure (3) and each biometric measure for cooling and noncooling for both cohorts.

Chapter 4: Results

Aim 1 (Fatigue and tremor in highly-skilled professions)

Musician Study

Keyboard and string musicians (n=30; average age 63.9 $\pm$ 7.5 years; age range 50-79 years; 11 males, 19 females) were recruited from the New Orleans area. Subjects had an average of 49.7 $\pm$ 12.5 years of experience (range: 10 - 75 years), and reported an average of 6.9 $\pm$ 5.6 hours/week of practice and/or performance (range: 0.5 – 20 hours/week). The following figures reflect skeletal muscle fatigue as determined by “time to functional fatigue” (or the time at which subjects reached below 70% of their baseline MVC), and physiologic tremor as a percentage of baseline tremor for each test session.

Table 4 juxtaposes each trial for the two conditions (cooling vs. noncooling) averaged across subjects, and Table 5 includes the two conditions averaged across trials. There is a large degree of variability in the data, as one can see from the standard deviations for each trial, which is appropriate considering individual differences and variability have been shown to increase with age. Therefore, subjects’ baseline amplitudes may be very different, but the values reported are always in comparison to their original values.

Table 4. Descriptive Statistics (cooling vs. noncooling), before transformation

		Mean	Std. Deviation
Pair 1	Tremor 1 cooling vs.	103.3831	50.38258
	Tremor 1 noncooling	151.9295	63.88873
Pair 2	Tremor 2 cooling vs.	104.1080	52.56067
	Tremor 2 noncooling	135.6675	72.39600
Pair 3	Tremor 3 cooling vs.	101.9949	48.63514
	Tremor 3 noncooling	152.3069	73.53802
Pair 4	Fatigue 1 cooling vs.	57.9218	41.00657
	Fatigue 1 noncooling	50.0616	36.06463
Pair 5	Fatigue 2 cooling vs.	56.8736	50.38756
	Fatigue 2 noncooling	56.3316	50.42071
Pair 6	Fatigue 3 cooling vs.	63.6736	48.55169
	Fatigue 3 noncooling	56.4596	58.42021

Table 5. Descriptive Statistics (Tremor Y-axis and Fatigue), averaged across trials, after transformation (natural log transform to normalize data)

	Mean	Std. Deviation
Tremor Cooling	4.5367	0.47358
Tremor Noncooling	4.9059	0.41864
Fatigue Cooling	3.8062	0.93901
Fatigue Noncooling	3.7932	0.74514

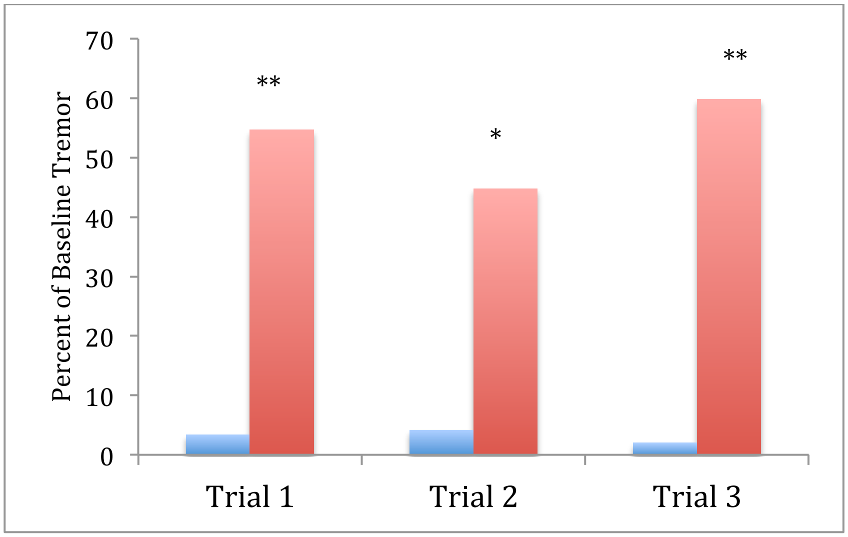

Figure 20. Musician Y-axis Tremor, Cooling vs. Noncooling

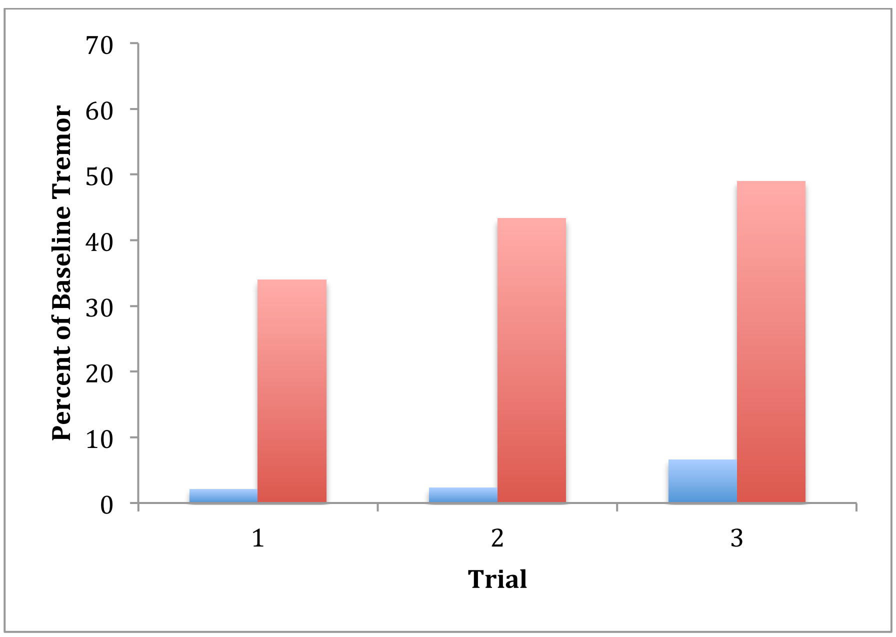

Figure 21. Musician Z-axis Tremor, Cooling vs. Noncooling

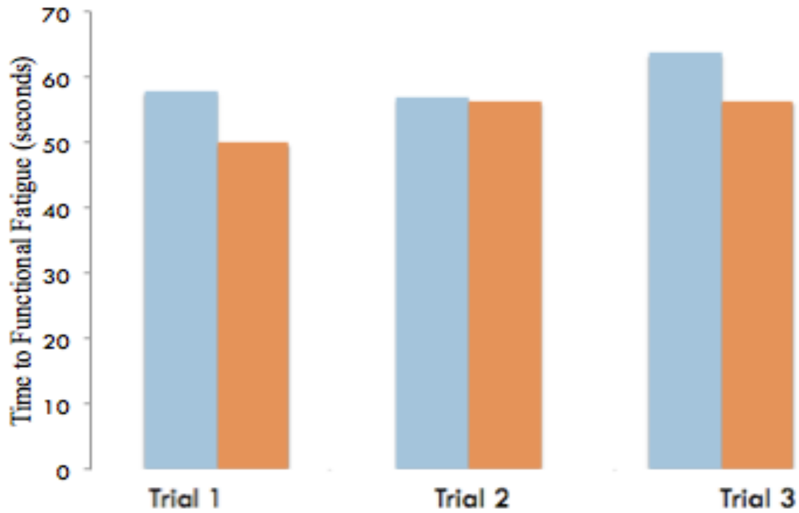

Figure 22. Musician Functional Fatigue, Cooling vs. Noncooling

Intermittent muscle cooling significantly reduced physiologic tremor in the y-axis for the first ($p<0.01$), second ($p<0.05$), and third ($p<0.01$) trials, as determined by a paired samples t-test (preliminary analysis) and is illustrated in Figure 20. Z-axis tremor was not determined to be significant and is illustrated in Figure 21. After completing a repeated measures ANOVA results showed a significant change ($p<0.001$) for muscle cooling in y-axis tremor, Wilks' Lambda= 0.406, $F(1,29) = 42.452$, $p <0.001$ (reference Table 6; remainder of SPSS outputs included in Appendix III). Significant changes in fatigue were not detected; Wilks' Lambda= 0.917, (F1, 29) = 2.640, $p =0.349$ (reference Table 6).

Data were normalized by transforming to natural log after which a repeated measures ANOVA was performed. Observed effect size was 0.43, yielded 83.2% power (alpha/type I error rate = 0.05). With trials for time to functional fatigue (Figure 22), there was a trend toward extension to fatigue but the effect was not significant.

Table 6. Multivariate Tests, y-axis tremor and fatigue

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Observed Power
Tremor	Wilks' Lambda	.406	42.452[b]	1.000	29.000	.000	.594	1.000
Fatigue	Wilks' Lambda	.917	2.640[b]	1.000	29.000	.115	.083	.349

Table 7. EMG Mean & Median Frequency Descriptive Statistics

MVC 3 Cooling				
	Mean F Average	Mean F Standard Deviation	Median F Average	Median F Standard Deviation
Cooling	121.0619244	74.95475481	111.2297867	60.65853558
Noncooling	119.5614004	65.93885851	110.6940489	50.1059874

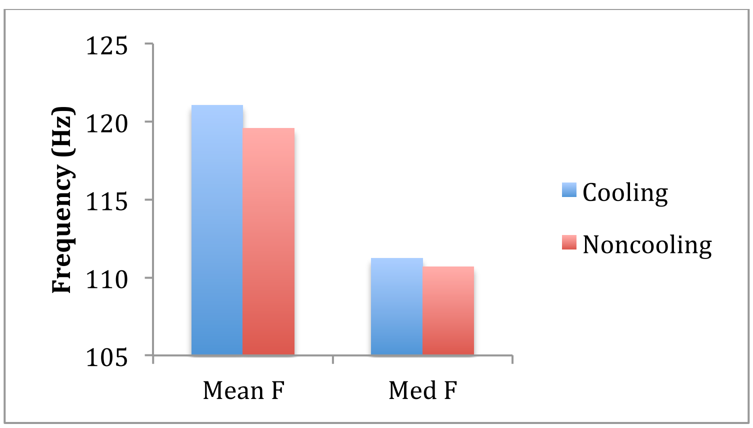

Figure 23. EMG frequency analysis of fatigue, averaged over subjects (Trial 3), Cooling vs Noncooling. Mean F= mean frequency; Med F= median frequency; [n=27 (three data files corrupted because the sensors fell off due to sweating)]

The EMG frequency detected a general downshift in both the median and median frequencies with the onset of fatigue, which is consistent with previously established literature. Also, as observed in Figure 23, there is less of a downshift in fatigue with muscle cooling, though not significant.

Surgeon study

For the surgeon study data, a paired sample t-test was used to compare means between cooling and noncooling for functional fatigue, tremor, and suture task measures. For the suture (Figure 24) and exercise (Figure 25) tasks, the original hypothesis that cooling would result in an extended time to fatigue and a shorter suture time was supported. Tremor values are reported as a percentage of baseline tremor (per axis); therefore, a tremor value of 0% would be the same as their baseline tremor.

Two cohorts of surgeons were recruited in the surgeon study: a novice surgeon cohort (<35 years) and a senior surgeon cohort (>50 years).

The novice surgeon cohort (n= 10; average age 31.2 $\pm$ 2.1 years; range 28-35 years) had 3.9 $\pm$ 2.3 years of surgical experience, worked 73.5 $\pm$ 7.4 hours/week, and spent 15.0 $\pm$ 11.3 hours/week in surgery. All subjects from the novice cohort were right handed, and exercised 4.8 $\pm$ 3.6 hours/week. Types of exercise included cardio/running/jogging (8), yoga (2), lifting (1), tennis (1), and kickball (1).

The experienced surgeon cohort (n= 9; average age 60.1 $\pm$ 8.0 years; range 50-79 years) had 36.4 $\pm$ 12.4 years of surgical experience, worked 60.0 $\pm$ 11.9 hours/week, and spent 20.6 $\pm$ 4.0 hours/week in surgery. All subjects from the experienced cohort were right handed (with the exception of one surgeon who was left hand dominant but sutured with his right hand), and exercised 7.4 $\pm$ 5.1 hours/week. Types of exercise included walking (5), swimming (2), lifting (2), tennis (3), and yoga (1).

Novice Cohort

Tremor in the novice surgeon cohort was highly variable across trials. The variability held true in values averaged over trials and individual trials as well (Table 8).

Table 8. Descriptive statistics for percent of baseline tremor in novice surgeons, per trial and averaged

Trial #	Condition	Mean	Standard Deviation
1	Cooling	8.45	54.34
	Noncooling	-8.33	40.51
2	Cooling	15.22	56.94
	Noncooling	-7.62	38.77
3	Cooling	20.25	32.26
	Noncooling	-6.28	39.71
Average	Cooling	14.64	47.85
	Noncooling	-7.41	39.66

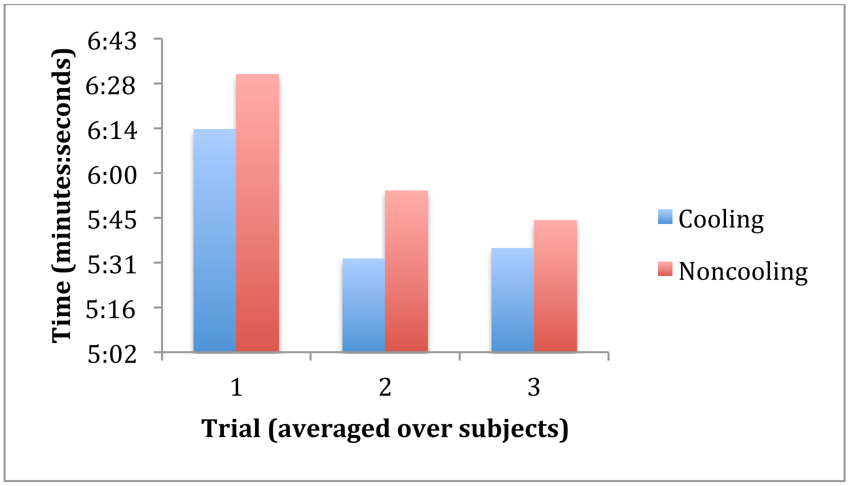

Figure 24. Timed suture task; novice surgeons

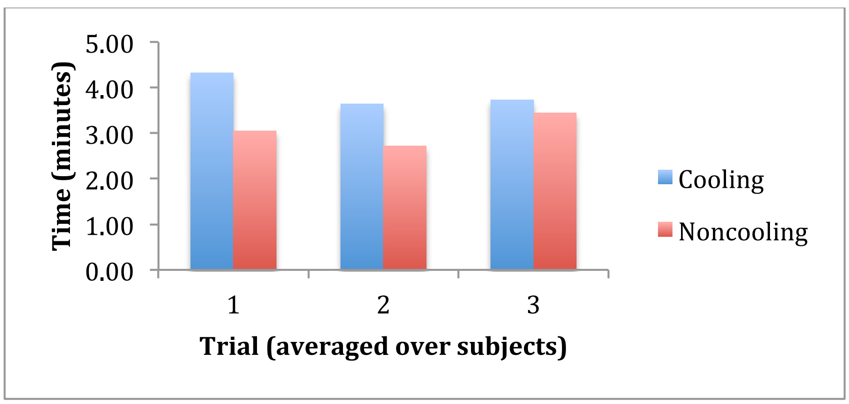

Figure 25. Time to fatigue in a weighted flexion/extension exercise; novice surgeons

For the functional fatigue (exercise) tasks, the hypothesis (cooling would result in an extended time to fatigue) was supported in both cohorts (Figures 25 and 29). Suture task times (Figures 24 and 28) also showed an improvement with muscle cooling in both cohorts, though the effect did not reach significance.

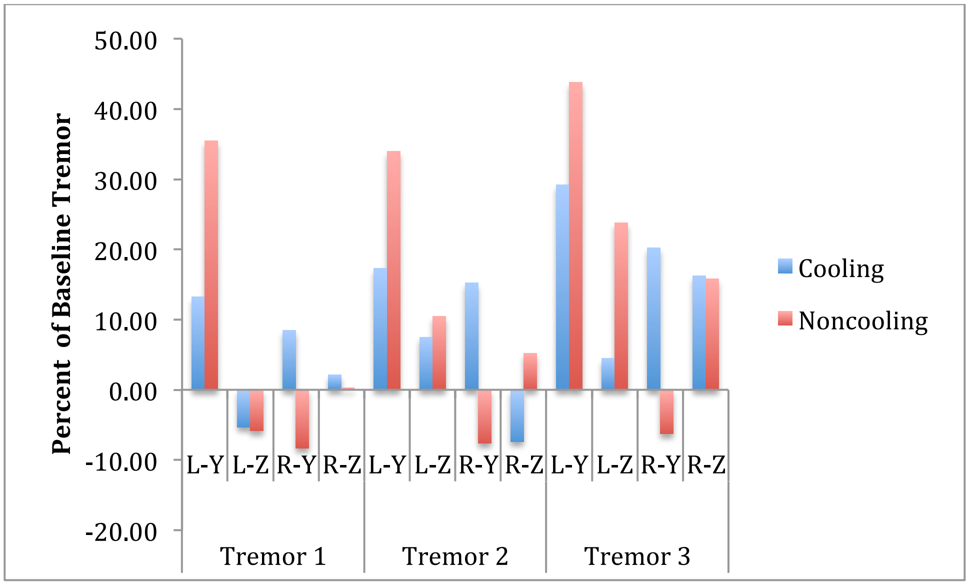

Figure 26. Bimanual Tremor, novice surgeons, per trial. [L= Left hand, R= Right hand; Y= y axis, Z= z axis]

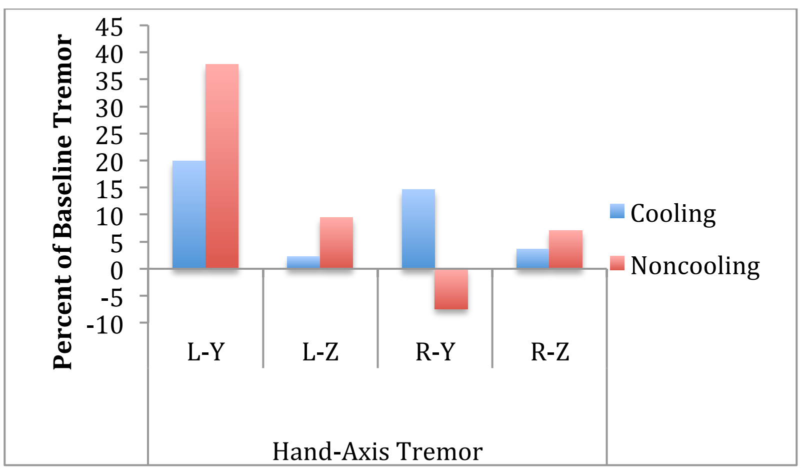

Figure 27. Bimanual tremor averaged over trials, novice surgeons. [L= Left hand, R= Right hand; Y= y axis, Z= z axis]

Experienced Cohort

With the senior surgeon cohort, the suture task results (Figure 26) did not support the hypothesis (suture time was consistently longer for cooling trials, though not significant), and the time to fatigue task (Figure 27) did support the hypothesis (time to fatigue was longer with cooling, though not significant). The tremor results, both per trial and averaged over trials for senior surgeons (Figures 29 and 30) illustrates a substantial effect of muscle cooling on tremor in both hands, with less learning than the novice surgeon cohort. The concept of task "learning" was introduced in the Methods chapter, and refers to the adaptation to a task with increasing familiarity.

Table 9. Descriptive statistics for % of baseline tremor in experienced surgeons, per trial and averaged

Trial #	Condition	Mean	Standard Deviation
1	Cooling	-7.06	41.34
	Noncooling	136.99	222.52
2	Cooling	60.37	60.37
	Noncooling	86.17	141.87
3	Cooling	-19.34	36.71
	Noncooling	185.83	291.59
Average	Cooling	11.32	46.14
	Noncooling	136.33	218.66

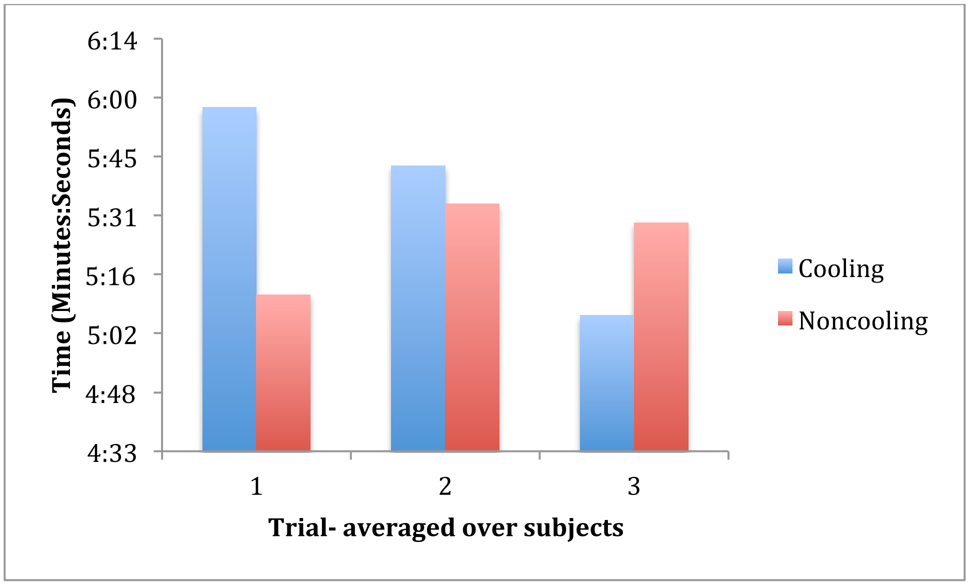

Figure 28. Timed suture task; experienced surgeons

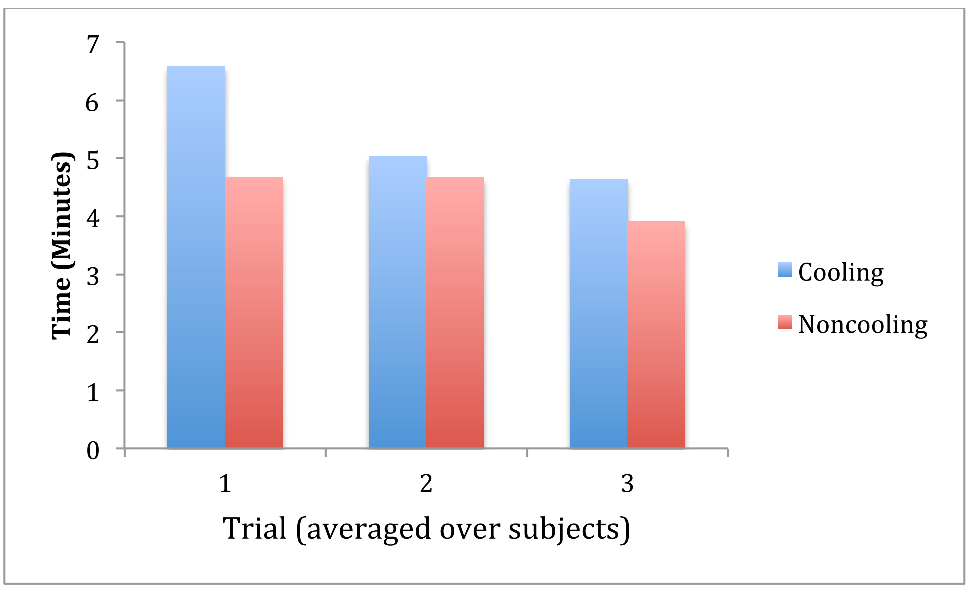

Figure 29. Time to fatigue in a weighted flexion/extension exercise; experienced surgeons

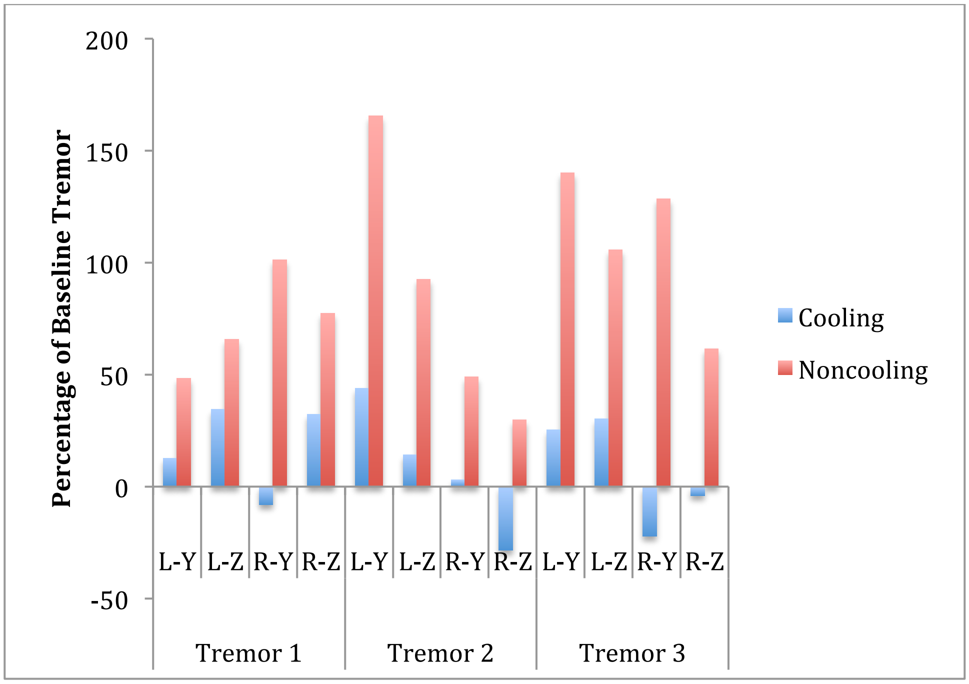

Figure 29. Bimanual Tremor per trial (experienced surgeons). [L= Left hand, R= Right hand; Y= y axis, Z= z axis]

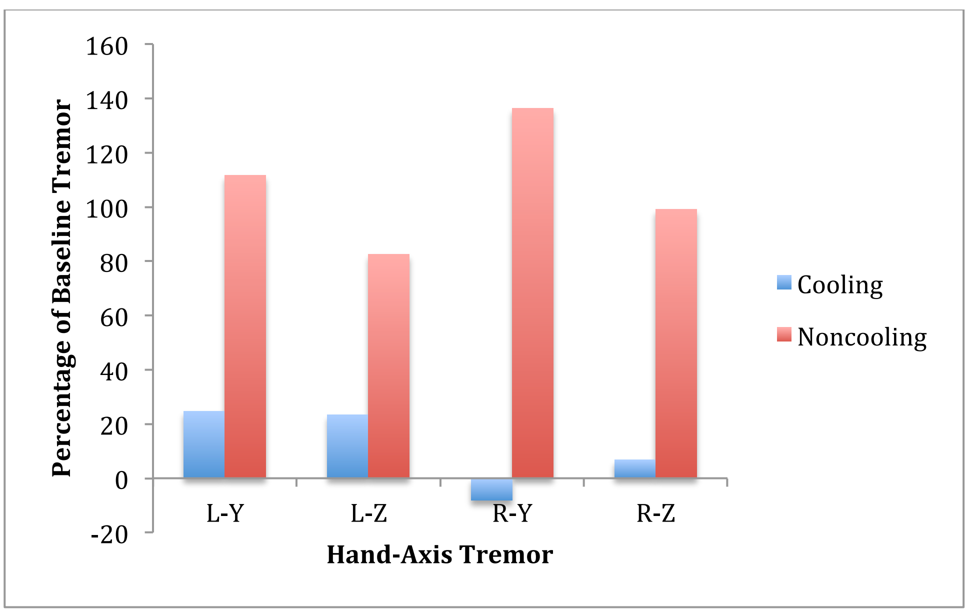

Figure 30. Bimanual tremor averaged over trials, experienced surgeons. [L= Left hand, R= Right hand; Y= y axis, Z= z axis]

Analysis indicated that experienced surgeons (Figure 31) showed a significant decrease in dominant hand tremor with the cooling condition ((t(8) = 1.89458; $p<0.05$), and had a larger tremor (compared to baseline) than novice surgeons in the noncooling condition; however, their noncooling tremor remained within baseline values. As depicted in Figure 31, experienced surgeon tremor remained at or near baseline values during noncooling trials, which differed significantly from cooling trials on both axes. Cooling trial values for experienced surgeons remained at similar values to the novice surgeon cohort.

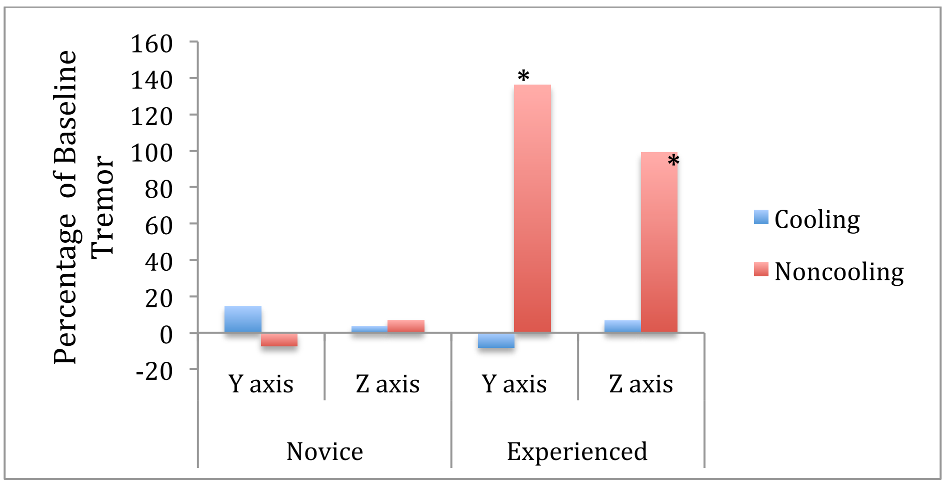

Figure 31. Bimanual tremor averaged over trials, both cohorts. [L= Left hand, R= Right hand; Y= y axis, Z= z axis]

Aim 2. Psychosocial Survey

It was hypothesized that experienced surgeons with greater levels of fatigue and tremor would have a higher age identity, higher levels of age stigma consciousness, and lower levels of occupational self-efficacy. Both cohorts were given the survey to maintain consistency within the study protocol; however, analysis of the novice surgeon cohort was not a goal of the research.

While all novice surgeons (n=10) completed the survey once, only 7 completed the survey both times (pre and post). For the experienced surgeon cohort (n=9), only 6 experienced surgeons completed the survey once and 5 completed it twice. Descriptive statistics from the first time each subject took the survey are included for both cohorts in Table 10 below.

Table 10. Descriptive Statistics, both cohorts.

Cohort	Survey Measure	Survey Time 1 Average ± Standard Deviation	Survey Time 2 Average ± Standard Deviation
Experienced	Age Identity	46.20 ± 9.91	48.20 ± 10.08
	SCQ Score (total possible = 33.6)	12.95 ± 1.74	13.71 ± 5.75
	OSE Scale (total possible= 42)	39.6 ± 2.88	38.20 ± 3.56
Novice	Age Identity	26.78 ± 3.42	26.83 ± 4.49
	SCQ Score (total possible = 33.6)	19.65 ± 4.29	13.89 ± 3.09
	OSE Scale (total possible= 42)	35.20 ± 5.92	33.43 ± 6.58

SCQ= Stigma Consciousness Questionnaire; OSE = Occupational Self Efficacy

Age Identity

The Age Identity measure was a single score question which asked, "Many people feel older or younger than they actually are. What age do you feel most of the time?" Only one surgeon from either cohort identified with an age that was greater than their actual age (and even then the difference was +2 years). The experienced surgeon cohort, on average, had an age identity of 48.5 $\pm$ 10.5 years (average of all responses), whereas their actual average age was 60.1 $\pm$ 8.0. The younger cohort's average actual age was 31.2 $\pm$ 2.1 and average age identity was 26.8 $\pm$ 3.4 (average of all responses; or 14.1% younger than their actual age).

Stigma Consciousness

The Stigma Consciousness Questionnaire (SCQ) was a 10-item Likert-style survey, with the maximum score possible 33.6. This questionnaire was adapted from another version of the survey for sexist stigma consciousness to reflect aging stigma consciousness. According to the literature (ex. women, gay and lesbians), high stigma consciousness scores indicated a greater likelihood that stereotypes would be perceived. The experienced surgeon cohort generally scored very low (13.4 $\pm$ 1.9 out of a total possible 33.6, averaged over all responses) on measures of stigma consciousness. From survey trial 1 to survey trial 2, the experienced surgeon responses did not change significantly but did increase from 12.95 to 13.71. The novice surgeon cohort scored slightly higher relative to experienced surgeons on measures of stigma consciousness (19.6 $\pm$ 4.2 out of a possible 33.6, average of all responses), and from survey trial 1 to survey trial 2 actually decreased from 19.65 to 13.89.

Occupational Self-Efficacy

The Occupational Self Efficacy (OSE) Scale was a 6-item Likert-style survey with a maximum possible score of 42. The "centrality" of occupational identity for surgeons was previously discussed (Onyura et al, 2015), and having a high OSE score was expected as surgeons developed confidence as their careers advanced. Experienced surgeons scored higher in OSE (average of 39.0 $\pm$ 3 out of a possible 42). From survey trial 1 to survey trial 2, experienced surgeons' OSE score decreased only one point (from 39.6 to 38.2). On average, novice surgeons scored slightly lower than experienced surgeons in occupational self-efficacy (average of 35.2 $\pm$ 5.9 out of a possible 42), and between trials novice surgeons scores only varied approximately 2 points, from 35.2 for survey trial 1 to 33.43 for survey trial 2.

Correlation Analysis

Correlational analyses were performed between each physical measure and psychological construct and the results are presented in Tables 11 and 12 (as age identity was a single-item score, only Stigma Consciousness and Occupational Self-Efficacy were included in these correlations). The two-tailed p-values for the respective correlation and subject number (n=5 for experienced surgeons, n=7 for novice surgeons) are reported in parentheses.

Table 11. Correlation between Stigma Consciousness Questionnaire score and biometric measures per condition (p-values in parentheses) (NC = noncooling, C = cooling)

Cohort	Trial #	Tremor NC	Tremor C	Time to Fatigue NC	Time to Fatigue C	Suture Time NC	Suture Time C
Exp'd	1	0.15 (0.80)	-0.83 (0.04)	0.49 (0.20)	0.49 (0.20)	0.33 (0.59)	0.0015 (<0.001)
	2	0.90 (0.04)	0.54 (0.35)	-0.14 (0.82)	0.57 (0.32)	-0.58 (0.31)	-0.53 (0.36)
Novice	1	0.17 (0.72)	-0.29 (0.53)	0.40 (0.37)	0.38 (0.4)	0.79 (0.03)	0.71 (0.07)
	2	0.66 (0.11)	-0.55 (0.20)	-0.19 (0.68)	-0.34 (0.46)	-0.09 (0.85)	-0.12 (0.80)

In Table 11, the novice cohort for suture time, indicated a greater SCQ score that correlated with a longer suture time for cooling and noncooling trials for the first survey trial (novice and training surgeons are often pressured to reduce suture times), but this effect was reversed in the second survey trial (suture time and stigma consciousness were uncorrelated, 0.09 for noncooling and 0.12 for cooling trials). Additionally, in the experienced cohort for cooling trials, correlation with suture time was much lower than with noncooling (0.001 for cooling versus 0.33 for noncooling) in survey trial 1, but this effect was not observed in the second trial survey.

Table 12. Correlation between Occupational Self-Efficacy score and Biometric measures (NC = noncooling, C = cooling)

Cohort	Trial #	Tremor NC	Tremor C	Time to Fatigue NC	Time to Fatigue C	Suture Time NC	Suture Time C
Exp'd	1	0.20 (0.75)	0.23 (0.71)	-0.61 (0.27)	0.12 (0.85)	-0.90 (0.04)	-0.995 (<0.001)
	2	-0.90 (0.04)	-0.48 (0.41)	-0.12 (0.85)	-0.63 (0.25)	0.001 (0.998)	-0.13 (0.83)
Novice	1	0.11 (0.81)	-0.18 (0.70)	0.78 (0.04)	0.45 (0.31)	-0.23 (0.62)	-0.20 (0.67)
	2	0.05 (0.83)	-0.17 (0.72)	0.61 (0.15)	0.30 (0.51)	-0.05 (0.83)	-0.15 (0.75)

For Table 12, the novice cohort exhibited low correlations for both cooling and noncooling trials for both survey response times. The novice cohort had consistently higher correlations with stigma consciousness (0.78 time 1 and 0.61 time 2) for noncooling fatigue trials, with a more moderate correlation for cooling fatigue trials (0.45 time 1 and 0.3 time 2). Correlations for experienced surgeons' responses between time 1 and time 2 for suture task cooling and noncooling trials were from 0.90 to 0.001 for noncooling from time 1 to time 2 and from .995 to 0.13 for cooling from time 1 to time 2. These data are discussed further in the last chapter.

Test-retest consistency and reliability was analyzed by correlating scores between time 1 and time 2 (pre-participation and post participation) for each cohort. The correlations between psychosocial measures are included in Table 13 for each cohort.

Table 13. Correlation of psychosocial measures between time 1 and time 2 per cohort (p values included in parentheses)

Cohort	Age Identity	Stigma Consciousness Questionnaire	Occupational Self-Efficacy
Experienced	0.50 (0.39)	-0.02 (0.97)	0.11 (0.86)
Novice	0.98 (<0.001)	0.65 (0.11)	0.75 (0.05)

To determine measures where subjects tended to change their answers, a correlation between the two survey response times was performed. Questions for which particular questions resulted in a <0.3 correlation were included in Table 14.

Table 14. Questions which had a correlation of < 0.30 from different survey measures

Cohort	Survey Measure	Question	Correlation
Experienced	Stigma Consciousness Questionnaire	I almost never think about my age when I interact with people.	-0.147
		Most people have a lot more ageist thoughts than they actually express.	0.281
		I often think that people are unfairly accused of being ageist.	0.218
	Occupational Self-Efficacy	I can remain calm when facing difficulties in surgery because I can rely on my abilities.	-0.25
		When I am confronted with a problem in surgery, I can usually find several solutions	0.167
		Whatever comes my way in surgery, I can usually handle it.	0.218
		My past experiences in surgery and medicine have prepared me well for my occupation	0.218
Novice	Stigma Consciousness Questionnaire	I never worry that my behaviors will be viewed as stereotypically old.	0.149
		When interacting with others, I feel like they interpret all my behaviors in terms of my age.	0.169
		I almost never think about my age when I interact with people.	-0.298
		Most people have a lot more ageist thoughts than they actually express.	0.072

Chapter 5: Discussion & Conclusions

The results of this study demonstrate that intermittent muscle cooling can be associated with reductions in physiologic tremor amplitude in aging surgeons and musicians. While muscle cooling did not significantly reduce functional fatigue as defined in this thesis for older musician and surgeon subjects, further investigation is warranted, as many subjects expressed not being adequately fatigued. With looming shortages in practicing surgeons, more research on the biometric, cognitive, and psychological implications of aging in surgery is needed for the medical field to appropriately navigate the transitional period during late-career clinical practice. Since such a large portion of the physician population is over 60 years of age, it would behoove hospitals and clinics to provide proper retirement planning initiatives for their employees to ensure a smooth transition out of clinical practice. Additionally, medical professionals should also look to adaptive ways to ease the physically demanding nature of the OR, and since cooling vests are already used by many surgeons to regulate temperature, modifying them to incorporate fatigue and tremor prevention would be the next logical step.

Musician study (Aim 1 – Part 1)

Just as professional athletes engage in preventative health measures, so should professionals in the arts and medicine. Muscle cooling consistently and significantly reduced activity-induced tremor in string and keyboard musicians. Measures of fatigue (time to fatigue and EMG) were more variable overall, making it difficult to provide significant conclusions. Data from this study does support initial assumptions, as the general negative trend in EMG mean and median frequencies is consistent with other research indicating the beginning of skeletal muscle fatigue. The data also demonstrated a trend toward extension in time to fatigue with cooling for each trial. There was a large degree of variability in the fatigue and tremor data, which surely had many contributing factors. The musicians recruited for the study presented in this thesis played a large range of music styles, instruments with different physical requirements, and even practiced different amounts of time on a daily or weekly basis. To improve the study with the goal of reducing variability, limiting subjects to only one primary instrument in addition to selecting subjects who practice and/or perform a similar amount throughout the week would be possible restrictions.

This research indicates that intermittent, localized muscle cooling has a therapeutic effect for activity-induced tremor. While the tremor data was only statistically significant on a single axis for musicians, the researchers involved in this work note that the activity performed by the subjects exceeded the limits of the equipment. Future research should consider the use of an accelerometer or freestanding tremor measure that could improve measurement of tremor on all three axes. While significant changes in fatigue were not reported, promising trends persisted in spite of the highly variable nature of fatigue corroborated in the literature. The physical demands of musical performance take a toll as musicians' age; thus, it is of particular importance to recognize and attempt to mitigate age associated decline for those professions that require fine motor control and dexterity to succeed. Muscle cooling could easily be incorporated into intermissions that are a common part of musical performances or, if the instrument is stationary (ex. piano) the musician could wear and regulate the cooling apparatus while performing.

Surgeon Study (Aim 1 – Part 2)

While other surgical editorials have repeatedly called for research on older surgeons, biometric evaluations of aging surgeons will remain limited until aging surgeons make themselves more available as research subjects. Early onset and chronic fatigue along with increases in tremor are inevitable and at the same time undesirable in the OR. Exercise-induced tremor, whether from one intense surgery or multiple surgeries can cause muscle strain and result in various injuries, which may be prevented through the use of better ergonomic design and potential muscle cooling therapies.

This research suggests that muscle-cooling therapies may benefit novice and experienced surgeons in reduction of tremor, and potentially increase time to functional fatigue. Due to the high variability rates commonly reported with fatigue and the small sample size in this study, it is difficult to broadly generalize the results reported in this thesis; however, promising results reported for both studies suggest that future investigation of muscle cooling in surgical tasks would elucidate the specific effects of targeted muscle cooling. Reduction or limiting confounding factors (daily caffeine intake, dietary considerations, time of day, whether or not the surgeon was on call the night before, etc.) was difficult and would have curtailed participation even further, but may have reduced some of the variability in the physical data acquired. While it was requested that surgeons try, for example, to consume the same amount of caffeine for both trials, this was impossible to enforce. For the suture task trials, some subjects had preconceived notions of the task, which may have influenced their performance. For fatigue trials, novice surgeons fatigued much more quickly suggesting some of them had not yet developed muscular endurance for laparoscopic tasks or overused muscles needlessly for the task. Many experienced subjects had excellent endurance and while these subjects eventually fatigued, it was clear that years of experience helped them to maintain their musculoskeletal abilities.

The positive results reported in this work highlight the interesting possibilities for investigating limb cooling with beta-blockers to determine if further reductions in tremor are capable with combined modalities. Certain surgical specialties (orthopedics, vascular surgery, ophthalmology) or those surgeons who fatigue quickly (either due to overwork, age, disability, etc.) may especially benefit from further research in this area. Many surgical journal editorials have specifically requested more longitudinal and cross-sectionals examination of aging surgeons and surgeons nearing retirement. The present trend of low sample sizes will continue to limit the capacity of these studies to establish accepted thresholds for surgeons or to stimulate future research. Another opportunity lies in the surgical simulation and training centers at medical schools, which have ample resources for self-evaluation of surgical skills and knowledge. Medical schools could incorporate these facilities to ensure surgeons of all ages and experience levels meet the current standards of medical practice.

Study Limitations

Consistent with previous attempts to quantify surgeon performance subject recruitment remained difficult with only one university hospital consenting to participate. Within the participating hospital a large portion of the available subject pool declined to take part claiming time constraints yet professed interest in the study's goals and outcomes. Anecdotal evidence suggests that limited participation in this and similar studies may reflect a concern about establishing unrealistic benchmarks for surgeon performance. Future studies attempting to recruit surgeon subjects should emphasize the potential contribution to dispelling the current negative bias toward older practitioners in addition to offering profession specific monetary or public recognition incentives.

Differences in workload between experienced and novice surgeons were significant (with novice surgeons working almost 20 hours more per week, on average). However, these work hours reflect the typical workload difference between the experienced and novice surgeon populations, and one would be hard pressed to find a surgical resident who worked less than 60 hours/week.

Since time constraints were such an issue in subject recruitment, future research would also benefit from modification of current surgical instruments to be able to measure limiting factors such as fatigue and tremor. However, many hospitals and surgeons may oppose real-time assessment of surgeon performance during surgery. Indeed, inviting data-gathering instrumentation into the operating room could provide an avenue for malpractice litigation should something go wrong. Perhaps this is why research has been so limited thus far, and perhaps why medical institutions have had obstacles in creating an objectively based system for evaluating surgeon performance.

Throughout medical training surgeons are also trained to develop ergonomically conducive body positions to help them maintain physical endurance in the OR, and an adequate/adjustable platform for tremor and suture measurement was provided for the surgeon study. The development of these skills also significantly assists surgeons in reducing tremor and the likelihood of overuse injury, not to mention facilitates successful and uneventful operations. To parse out these skills between novice surgeons and surgeons nearing retirement would require significantly more advanced motion and electromyographic analysis, but would surely offer invaluable information on the ergonomics of surgery. Longitudinal research to look at how individual surgeons develop these skills over time would be difficult to conduct but would also offer the potential to reduce training times for medical schools and possibly make surgeries involving more novice surgeons safer.

Psychosocial Surgeon Survey (Aim 2)

The concept of age stigma in the aging physician is a particularly sensitive topic in the professional medical society. The issue of medical malpractice risk is surely pressing, but a more widespread concern is the surgeon's self-identity, which may prevent healthy views of retirement and therefore hinder proper retirement planning. Furthermore, stigmatization of aging surgeons reduces many senior surgeons' willingness to discuss the physical, cognitive, and psychological changes that occur over the course of a career in surgery. This stigmatization creates an obstacle for many surgeons who should be planning for a healthy transition to retirement. An over awareness of age stigma may also influence novice and experienced surgeons to over perform, especially in a testing situation when they are aware of their skills being recorded for extensive analysis. A slightly different but similar concept is that of age identity, the age one identifies with, may affect how one perceives different aspects of aging and the workplace environment. Surgeons and musicians are esteemed professions and age identity and its manifestations in everyday life for these professions are crucial to their success. Occupational self-efficacy (OSE) is yet another measure meant to ascertain whether an individual feels they can competently perform their job. While OSE is a very comprehensive measure that takes into account both physical, mental, and cognitive performance, if a surgeon were not physically able to operate this would be reflected in a lower OSE score.

For the age identity measure reported in this work, experienced surgeons felt an average of 19.2% younger than their actual age, which is strikingly close to the previously referenced literature on adults age 40+ identifying as 20% younger on average (Rubin and Berntsen, 2006). The established consistency in age identity could provide protective effects against negative aging stereotypes in the workplace. One unanticipated observation gleaned from the survey work was the concept of age stigma against novice surgeons being harmful to their professional development (expressed by more than one novice subject). The younger cohort's average actual age was 14.1% younger than their actual age, which is also on par with previously discussed data (those 25 and older report subjective age as ~20% younger). Many novice surgeon subjects expressed negative stereotype experiences, perhaps identifying as younger is part of a coping mechanism to rationalize them being treated as younger. This might provide a reason for the skew of older surgeons having a relatively young age identity, as their health and socioeconomic status are generally much higher than that of the general population.

It was expected that those surgeons who scored high on the SCQ were more likely to perceive and process stereotypes (whether positive or negative), and might therefore be more perceptive to negative stereotype threat and embodiment. The experienced surgeon cohort generally scored very low (13.4 $\pm$ 1.9 out of a total possible 33.6, scores averaged overall) on measures of stigma consciousness, suggesting that if they experience ageist stereotypes on a normal basis, they may not perceive them as such. The novice surgeon cohort scored slightly higher relative to experienced surgeons on measures of stigma consciousness (19.6 ± 4.2 out of a possible 33.6, scored averaged overall), indicating this cohort might be more aware of negative age stereotypes and stigma. OSE results were as expected, as novice surgeons have not had the 20+ years of experience in the OR that give experienced surgeons the skills and confidence to successfully perform on a day-to-day basis.

Correlation Analysis

Both cohorts expressed relatively low levels of stigma consciousness overall. Table 11 listed the correlation values between participants SCQ score and different biometric measures from Aim 1. For noncooling tremor trials, stigma consciousness responses for experienced surgeons changed from 0.15 to 0.90, possibly indicating a greater awareness of age stigma with testing. Between survey time 1 and time 2 for experienced surgeons, correlation between SCQ score and suture task cooling trials (from <0.01 to -0.53), indicated an even lower presence of stigma consciousness after exposure to testing (or possibly due to the hypothesized protective effect of the cooling garment). For cooling trials and tremor, there was a strong negative correlation for experienced surgeons (-0.83 for cooling versus -0.15 for noncooling) for survey trial 1, whereas the effect seemingly reversed for survey trial 2 (0.90 for noncooling and 0.54 for cooling).

Novice surgeons' correlational values remained generally the same between cooling and noncooling for biometric measures with a few exceptions. For the suture task in novice surgeons their SCQ score decreased from 0.79 to -0.09 from time 1 to time 2, indicating they were either less conscious of age stigma or more confident about the task. This was consistent with noncooling trials (0.71 for time 1 to -0.12 for time 2).

Both cohorts scored high (experienced surgeons scoring slightly higher on average) for occupational self-efficacy. Experienced surgeons correlations between OSE and biometric measures varied only slightly between cooling and noncooling trials (Table 12). As for changes in correlation between survey trials for experienced surgeons, noncooling tremor trials initially had a 0.20 correlation with OSE, and the second trial resulted in a -0.90 correlation (p value < 0.05), this drop might reflect experienced surgeons exposure to age-related testing. Both cooling and noncooling suture trials for the experienced cohort had a highly negative correlation for survey time 1 (-0.90 for noncooling and -.995 for cooling, both of which were significant), indicating those surgeons who had a high OSE score performed sutures quicker/shorter, which is consistent with the data. Novice surgeons had consistently low correlations for OSE and tremor (both cooling and noncooling). Considering novice surgeons typically had very low levels of tremor, this might indicate an area of expertise where they feel less confident. Similarly, novice surgeons also had low correlations between OSE and suture time as well (for cooling and noncooling trials).

Experienced surgeon scores varied between the survey results before testing compared to post testing survey responses. Of note were the large variations for the measures of stigma consciousness and occupational self-efficacy (correlation of less than 0.3, see Table 13). Therefore, it is possible that exposure to testing altered their perceptions of age stigma and self-efficacy, but not as much for age identity. For the novice surgeon cohort, testing did not alter their responses nearly as much. There are a few explanations for this, such as novice cohorts don't have the depth and breadth of knowledge many experienced surgeons have making them less able to self-assess (or less likely to change their answers). Also, as individual differences in physical and cognitive measures grow as we age, younger subjects tend to show less variability. The difference in responses before and after testing supports the original hypothesis that exposure to testing related to aging might alter older surgeons' perceptions of occupational self-efficacy and age stigma consciousness.

Those questions which had the largest degree of correlation for the experienced cohort for stigma consciousness all encompasses ways in which people perceive how they are treated in terms of their age. Those questions that subjects answered differently for OSE focused on situations where exceptions in surgery test your ability to perform adequately. In the novice surgeon cohort, the only questions that had low correlations were from the stigma consciousness questionnaire (1. I never worry that my behaviors will be viewed as stereotypically old, 2. When interacting with others, I feel like they interpret all my behaviors in terms of my age, 3. I almost never think about my age when I interact with people, and 4. Most people have a lot more ageist thoughts than they actually express.) The 4th question (Most people have a lot more ageist thoughts than they actually express) was reflected and voiced by several novice subjects, emphasizing that they felt targeted and judged because many more experienced surgeons and even patients equivocated looking "younger" also meant less experienced and/or less competent.

It is recognized that such a small sample size limits the scope of these interpretations however a focal point for this research was to open up the discussion of age stigma and the psychological constructs to explore areas of relevance to surgeons nearing retirement.

There is also the possibility that the questions from these measures did not adequately transfer or apply to aging surgeons. The SCQ was initially designed to test for stigma in marginalized groups such as the LGBTQ community, racial minorities, and women; modification of the wording of the survey to target those subject to ageism could have misgivings. Additionally, the OSE score was designed for the general workforce, and applying the measure to such a highly trained profession has yet to be validated. Lastly, it is possible that surgeons were fatigued or rushed and simply had less interest in the questions the second time taking the survey.

Conclusions

As more research becomes available on surgeon aging and emphasis from colleagues and hospital administrators focuses more on acceptance of surgeon changes due to the natural aging process, it is important for surgeons nearing retirement to consider their elevated status and expansive experience as an opportunity for research and learning. This will be critical for medicine to better understand how surgeons adapt to aging in and out of the operating room environment. Not only should hospitals and clinics adopt a more proactive approach to guiding surgeon retirement, research and discussion groups at medical conferences should explore these pertinent issues. With the aging of the general workforce both in the United States and globally, incorporation of older individuals who wish to work past typical retirement age will protect these individuals not only from poverty but might also from aging-related mental and physical illness due to inactivity and isolation. The data collected and presented here generally falls in line with other data available on age identity, stigma consciousness, and self-efficacy. It would be helpful to further delineate these concepts and incorporate them into retirement planning and awareness, not only for medical specialists but for other professions as well.

To date, this is arguably the most extensive task-related research conducted that specifically compares novice surgeons to aging surgeons nearing retirement. Research in the medical field tends to focus on comparing novice surgeons to experienced ones (Suzuki et al, 2015), but consider any surgeon with 5+ years post-residency as experienced, as opposed to focusing on the physical and cognitive obstacles facing older surgeons near retirement. The applications of this research could extend far beyond the operating rooms to benefit other older adults', who experience exacerbated tremor in their professions (mechanics, painters, jewelers, etc.) or their hobbies. Parkinsonian and essential tremors have been reduced with muscle cooling, and menopausal hot flashes are reduced in severity and frequency when overnight cooling is implemented. Further investigation as to whether muscle cooling could mollify similar pathologies is warranted. Muscle cooling is already a popular recovery and therapy method in professional athletes and sports trainers, and translational research to incorporate these therapies into other genres could benefit population at large.

The importance of baseline performance measures for everything from cognitive performance to physical fatigue cannot be understated in aging professionals. Acceptable baseline measures need to be established so that reliable measures can be applied in determining how much fatigue or tremor is too much, especially in the OR. As more documentation in this research area occurs, both cross-sectional and longitudinal information on surgeon performance will greatly benefit the community of practitioners globally. However, advancements in research will heavily rely on a shift in attitude toward development of objective assessment tools to either incorporate into the operating room or facilitate and require testing outside the operating room. Once these attitudes change, further advancements in medicine can be made, hopefully resulting in safer and more efficient operating rooms for the surgeons and their patients.

Appendix I. Online Survey through Qualtrics—Survey Questions

I. Age Idendity

1. Many people feel older or younger than they actually are. What age do you feel most of the time?

II. Stigma Consciousness Questionnaire. The following questions will be scored from 1 to 7, 1 being never and 7 being always.

1. Stereotypes about aging have not affected me personally.
2. I never worry that my behaviors will be viewed as stereotypically old.
3. When interacting with others, I feel like they interpret all my behaviors in terms of my age.
4. Most people do not judge others on the basis of their age.
5. My age does not influence how others act with me.
6. I almost never think about my age when I interact with people.
7. My age does not influence how people act with me.

8. Most people have a lot more ageist thoughts than they actually express.

9. I often think that people are unfairly accused of being ageist.

10. Most people have a problem viewing older adults as equals.

III. Occupational Self-Efficacy. The following questions will be scored from 1 to 7, 1 being never and 7 being always.

1. I can remain calm when facing difficulties in my job because I can rely on my abilities.

2. When I am confronted with a problem in my job, I can usually find several solutions.

3. Whatever comes my way in my job, I can usually handle it.

4. My past experiences in my job have prepared me well for my occupational future.

5. I meet the goals that I set for myself in my job.

6. I feel prepared for most of the demands in my job.

Appendix II

Design elements of surgeon-specific cooling garments for surgeons

Several design factors were considered in order to develop a cooling garment for surgeons. Investigation of the available literature on surgeon muscle fatigue and cooling strategies was used to design the basic garment. Information was gathered during OR visits to gain better understanding of the physical and temporal constraints endured by surgeons. Surgeon interviews were conducted to gauge concerns involving fatigue induction and the feasibility of future suit implementation for the OR. Initial prototypes were built using this knowledge and evaluated by the principal investigators so as not to limit our surgeon subject population for testing.

Muscular demands of surgery were analyzed (discussed previously in the literature review) and muscles that fatigued quickly in general surgery (deltoids, brachioradialis) were given priority in the design. While several surgical specialties exist, each with their own muscle demands and anatomical constraints, this study focused on the limitations inherent to general surgery since this was the most applicable across surgical disciplines. While much of the literature on surgeon fatigue focuses on laparoscopic surgery, many older surgeons are not as experienced in laparoscopic suturing. Therefore, to ensure all subjects are tasked with the same level of difficulty, a non-laparoscopic task was designed and implemented.

After extensive assessment, the suit was designed to target the following muscular regions: superficial flexor and extensor forearm regions, superficial extrinsic muscles of the shoulder scapular region.

a. superficial anterior forearm muscle region: pronator teres (pronates forearm, assists in flexion), flexor carpi radialis (flexes hand, assists in abduction), palamris longus (flexes hand and tenses palmar fascia), flexor carpi ulnaris (flexes hand, assists in adduction), flexor digitorum suprerficialis (flexes middle and proximal phalanges of index, middle, ring and little finger, assists in hand flexion).
b. superficial posterior forearm muscle region: brachioradialis (flexes forearm), extensor carpi radialis longus (extends wrist and abducts hand), extensor carpi radialis brevis (extends wrist and abducts hand), extensor digitorum (extends index, middle, ring and little fingers; assists in wrist extension), extensor carpi ulnaris (extends wrist and adducts hand), anconeus (assists triceps brachii in extending forearm).
c. superficial extrinsic muscles of the scapular region: trapezius (elevates scapula, retracts scapula, depresses scapula, rotates scapula) and the latissimus dorsi (extends, adducts, and medially rotates arm, draws shoulder downward and backward).
d. superficial intrinsic target muscles of the scapular region: deltoid (clavicular part-flexes and medially rotates arm, acromial part-abducts arm, spinal part-extends and laterally rotates arm), supraspinatus (initiates arm abduction, acts with rotator cuff muscles), infraspinatus (lateral rotation of arm with teres minor), teres minor (adducts and medially rotates arm), and subscapularis (medially rotates arm and adducts it)

Additional materials used for the cooling element of the garment were evaluated to determine conductivity rates for tubing materials (Tygon medical tubing). Systematic testing was completed both with and without a subject wearing the garment. Pilot designs were tested with volunteer surgeons who were made aware of the purpose and aim of the suit's capabilities. Tests were completed to determine the efficacy of the chiller. The recirculating chiller (Isotemp) reached steady state cooling for 15 minutes prior to testing. Thermal sensors (Biopac SKT100C hardware unit and corresponding sensors) were placed at the intersection of the valve and tubing for input and output of the bag. Readings were then taken every minute for 10 minutes Additionally; there was no change when the temperature sensors were moved to the tubing right at the chiller outlet. Based on acquired data, no significant changes in temperature were found to suggest altering the methodology for surgeon cooling.

Other materials testing included thermal sensors placed at the inlet and outlet of the suit while worn by a subject, and temperature readings were taken every minute for ten minutes. There appears to be an initial spike where the output temperature increased before decreasing toward equilibrium with input temperature. Further testing, during which the subject's skin temperature was taken, would be needed to determine if this temperature spike was due to the subject's body attempting to maintain homeostasis or some other cause.

From surgeon interviews and operating room observations, it was determined that the unit must be compact and the garment must be comfortable. Mobility of the surgeon in the operating room is tantamount to the implementation of this device. If the surgeon is significantly hindered or made to feel limited then the purpose of the cooling garment and its therapeutic effects would essentially be negated. Therefore the entire system must be compact enough so as not to result in interference with any operating room personnel or equipment. Commercial chillers used by the lab are approximately the size of a carry-on suitcase, only require a standard electrical outlet, and can be easily moved with a cart.

Current cooling technology consists of several LCWG adaptations. Design barriers for maximizing thermal transfer between the LCWG and the skin include garment material, proximity of material to the skin, and weight of the garment. The design implemented by our lab used small plastic tubing to recirculate cold water through the LCWG over previously defined muscular regions. Design elements for the suit involve targeting specific thermogenic zones (shoulder, upper back, and forearm areas) for cooling muscle groups.

Appendix III. SPSS output of Musician Research Study

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Tremor	Sphericity Assumed	2.045	1	2.045	11.279	.002	.280	11.279	.901
	Greenhouse-Geisser	2.045	1.000	2.045	11.279	.002	.280	11.279	.901
	Huynh-Feldt	2.045	1.000	2.045	11.279	.002	.280	11.279	.901
	Lower-bound	2.045	1.000	2.045	11.279	.002	.280	11.279	.901
Error(Temperature)	Sphericity Assumed	5.257	29	.181					
	Greenhouse-Geisser	5.257	29.000	.181					
	Huynh-Feldt	5.257	29.000	.181					
	Lower-bound	5.257	29.000	.181					

Table 1. Tremor (Y-axis) Tests of Within-Subjects Effects (transformed using the natural log)

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Fatigue	Sphericity Assumed	.003	1	.003	.006	.941	.000	.006	.051
	Greenhouse-Geisser	.003	1.000	.003	.006	.941	.000	.006	.051
	Huynh-Feldt	.003	1.000	.003	.006	.941	.000	.006	.051
	Lower-bound	.003	1.000	.003	.006	.941	.000	.006	.051
Error(Fatigue)	Sphericity Assumed	13.138	29	.453					
	Greenhouse-Geisser	13.138	29.000	.453					
	Huynh-Feldt	13.138	29.000	.453					
	Lower-bound	13.138	29.000	.453					

Table 2. Fatigue, Tests of Within-Subjects Effects

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