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Journal of Undergraduate Research



Volume Ten
Issue One, Fall 2011

University of Rochester

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From the Editors

In our relatively short eight-year history, our editorial staff at Journal of Undergraduate Research has worked diligently to showcase the formidable contributions of Rochester undergraduates to academic research. Our past editors have frequently pointed out the unique benefits that research can confer to the undergraduate learning experience and to professional success post graduation. However, the question is no longer “Why should undergraduates engage in research?” Given the dramatically increased number of submissions we have reviewed this semester, the articles presented in this issue put that question to rest—they represent a new, and certainly more competitive, stage of undergraduate academic involvement.

With the articles in this issue, we hope to show that the excitement of this new stage in undergraduate research has broadened to the three core areas: the natural sciences, social sciences, and humanities. The topics in the following pages discuss pressing questions in biomedical engineering, healthcare, trade policy, theology, and physics. Our authors will undoubtedly inspire subsequent groups of researchers and students to improve upon the ideas they express herein. To honor their accomplishments we now pose a new question to our readers: How, and in what manner, should undergraduates engage in research? As educated consumers of research, how can we best extend our education beyond the classroom to make our understanding of the world ever better? Journal of Undergraduate Research will continue to provide a forum for these questions under the University of Rochester’s guiding principle, *Meliora*.

Sincerely,
Sthuthi David and Cameron LaPoint

Sincerely,

Sthuthi David and Cameron LaPoint

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Journal of Undergraduate Research

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About the Journal

The Journal of Undergraduate Research, Volume 10, Issues 1, Fall 2011 was assembled on a Windows 7 PC using Adobe InDesign CS6. Graphics were produced using Adobe Photoshop CS5 and Adobe Illustrator CS5. Microsoft Office was used for text editing and review. Fonts used included Arial, Symbol (for Greek characters), and Garamond. This journal was perfectly bound by Mercury Print Productions, Rochester, NY.

Self-Flagellation as Sanctification in the Roman Catholic Church's Prelature of the Holy Cross and Opus Dei

Andrew Nicholas Cirillo, 2012

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Defining religious ritual as something that harbors faith more deeply through the practice of a dramatic, yet spiritual act of gravity, we can see that corporal mortification is one way this can be done. The society of Opus Dei's rituals of corporal mortification, and most specifically the one dealing with self-flagellation, is what I will put into the most careful consideration within this paper. In addition to the attention that the movie *The Da Vinci Code* has placed on Opus Dei, the overall action of corporal mortification can be seen by present society as appalling and outrageous. However, using the viewpoints and objectivities of such ritual explication as symbolism, performance theory, and rite of passage, I argue that the ritual process of self-flagellation, specifically for the organization of Opus Dei, is one that fosters an ideal way to live, and one which fulfills the overall goal of life here on earth: sanctifying yourself and others to be closer to God.

INTRODUCTION

In the modern era, people try to avoid pain at all costs, whether it be psychological, physical, or even spiritual. Western society takes pride in providing the best doctors with the best pharmaceutical products and pain-reducing techniques to provide patients with the most technologically advanced healthcare. After all, medicine has come a long way since Hippocrates laid out the first basic medical guidelines in his *Corpus Hippocraticum*. Nevertheless, the central point remains that people do not want pain, or anything to do with it. It causes sickness, depression, loss of self-confidence, and worst of all, death. However, what if pain was to be considered acceptable in ritual practice? This is the case in many religions all over the world, including that of Christianity. As the media has recently centered on the Catholic religious group of Opus Dei and its usage of corporal mortification, especially evident in the popular book and film *The Da Vinci Code*, we have to be more concerned with how corporal mortification is religiously feasible.

In this paper, I focus on Opus Dei's ritual practice of self-flagellation. I examine the physical as well as the mental aspects that members foster from such a ritual practice of corporal mortification. This technique, although not exclusive to the

traditionalist Catholic sect, holds much significance in its weekly occurrence amid the presence of prayer. First, I will discuss the background of Opus Dei in order to provide a general layout of how such strict bodily penitence came about. The main goal, aside from the aforementioned objective to explain the ritual to the reader, is to apply various theories to the ritual of self-flagellation, and to explain what is really happening in the eyes of a practitioner of this exercise of faith. I will talk about this more soundly in the following paragraphs, but first, ritual and its all-encompassing generalities will be discussed, so as to relate to what the theorists can apply toward the practices carried out by Opus Dei.

RITUAL IN GENERAL

What does one normally think when the word "ritual" comes to mind? Is it something sacred or fantastic, something moving or symbolic, and/or something performative or dramatic? All of these terms can be applied to such a word, especially concerning its religious connotation. What the ritual actors focus on is mostly the symbolic and performative components of what can often times be compared to a theatrical production. Aside from these elements comes overwhelmingly the idea of liminality, or the idea behind stages of progress while the performer of the ritual witnesses and takes part in a process of change. This change, both spiritual and physical, oftentimes is what separates simple theater from religious rituals. So, what does one procure from these rituals? By performing these rituals repeatedly, one grows in his/her faith and develops a standard of beliefs so that the ideas behind the institution in charge of the ritual seem to hold valid truths within society. In this paper, the central religious ritual discussed and elaborated upon will be that of self-flagellation in the only personal prelature of the Roman Catholic Church. Of course, what is written above concerns the controversial group of both religious and lay members of Opus Dei, translated from Latin to mean "God's work." First, I will center on performance theory, most notably prescribed by Roy Rappaport. Rappaport's vision of ritual as a "performance of more or less invariant sequences of formal acts and utterances not encoded by the performers"¹ applies perfectly to the

ritualized action of whipping. Although some ascetics would consider themselves as creators of the ritual, it has existed for centuries as a form of penitence and as an imitation of Christ's suffering on his last days on Earth. When we finally move from a performance background to a more in-depth analysis surrounding the actual stages of the ritual itself, I will exercise the writings of both Arnold van Gennep and Victor W. Turner, using their revision on the traditional rites of passage, including liminality. Therefore, I will explain the physical actualization of carrying out the flagellating act and then subsequently move toward the purifying and spiritual "rite[s] which accompany every change of place, state, social position and age."²² Throughout the paper, I will expound upon the symbols, both physical and psychological, of the action itself. I will provide a description of not only the individual tools used within the ritual, but also of each separate action of mental choice and deliberation that carries weight on how important the ritual is to the members of Opus Dei. Only through these religious and sociological theories can we truly understand and recognize such a pain-inducing ritual.

By using the historical and theoretical approaches mentioned above, I argue not only for the clarification of ritualized whipping within Opus Dei, but also that it functions mentally as a ritual of purification through means of sacrificing the comfort of the body to experience the similar suffering of Christ. Through this suffering, the Christian identity of "sanctification through work" presents itself as a cleansing step toward the divine.

BACKGROUND

Opus Dei was, and is, an organization of membership and community, with a striking contrast of individuality as well, even more so than might be thought. John Allen states, "At the level of individual initiative, Opus Dei members are generally committed Catholics involved in their parishes, their dioceses, and other aspects of the life of the Church,"²³ but at the same time "It's only at the personal level that people are asked to 'do' Opus Dei,"²⁴ creating their own personal sanctification through membership. Formed over the course of his life by Josemaría Escrivá de Balaguer of Aragon, Spain, Opus Dei was something Escrivá had seen in a vision telling him to do God's work: "He saw Opus Dei, as the Lord wanted it and as it would be, down through the centuries."²⁵ From October 2, 1928, onward, the Spanish priest elevated his idea of the sanctification of life onto the Vatican, which finally was approved and recognized as a personal prelature in 1982 by Pope John Paul II.

The central tenet within Opus Dei thought, belief, and membership, is that "to be holy means to sanctify work itself, to sanctify oneself in work, and to sanctify others with work,"²⁶ and thus, "Escrivá's conception [of] personal sanctification through work is inextricably linked to the apostolic vocation of the Christian, to 'the apostolic mission through work.'"²⁷ This is central to members of Opus Dei and truly limits them to a boundary set of guidelines to live by. As Michael Walsh puts it simply and comprehensively:

In his apostolate the Opus Dei member is exhorted 'Esto vir: Be a man' (Maxim 4), a man of will-power, energy, example (Maxim 11), whose motto is 'God and daring' (Maxim 401). He

is ambitious—for knowledge, for leadership, for great adventures (Maxim 24). He remembers that his heart is a traitor (Maxim 188), and that it is beautiful to be a victim (Maxim 175). He is uncompromising, for to compromise is a sure sign of not possessing the truth (Maxim 394)...he needs to be strong, for 'The plan of sanctity that God asks of us is determined by these three points: holy intransigence, holy coercion, and holy shamelessness' (Maxim 387).⁸

These demands often come hard on those members who join and on those who do not understand the concepts fully. As a former numerary, María del Carmen Tapia states, "I was cut off from my entire family. This ostracism lasted eighteen years, exactly the time of my stay in Opus Dei."⁹ However, for most of the members, including the numeraries, priests, and numerary assistants, ostracism is not a problem, as they, albeit having other professions in life, are mostly dedicated to the care of and commitment to Opus Dei households and their members.

STRUCTURE

Numeraries, the most controversial subset of the Opus Dei membership, are those who are extremely devoted to Opus Dei. These positions are restricted to "members who make Opus Dei their immediate family."¹⁰ Despite "remaining lay, [they] pledge celibacy, live together in one of about 1,700 sex-segregated 'centers' and extend their training to a degree rivaling a priest's."¹¹ Numerary assistants are relatively similar to their numerary counterparts, but often are women who take on the traditional role of cleaning and cooking. Furthermore, there are members who have equivalent responsibilities to numeraries, who are called associates. The only difference lies in their residency with family members instead of at an Opus Dei center. Aside from all these roles lie the most prevalent members, the supernumeraries, who are not celibate-bound and who do not live within Opus Dei households. Often required to seek out "spiritual direction from a numerary of Opus Dei,"¹² they also support the association financially with regular monetary gifts.

In addition to the various lay members of the organization, there exist clergymen, bishops, priests, and deacons, as well as the supreme leader of the prelature itself, currently Prelate Bishop Javier Echevarría Rodríguez. The other half of the society namely comes from the governing organization of the Priestly Society of the Holy Cross. Although the ordained members "comprise only about 3 percent of the total membership,"¹³ they have the most power and the most senior spiritual direction to guide the numerary members, who then take responsibility for the formation of the remainder of the members.

CORPORAL MORTIFICATION

Above, I have laid out a basis and history of the organization so the reader can now begin to understand just how corporal mortification works within the society. The idea of inflicting pain on one's body, both physically and mentally, has been part of religious practice for centuries. Not limiting itself to Christianity, there are numerous examples of corporal mortification in such rituals as the Remembrance of Muharram in Shi'a Islam and the Thiapusam Festival in Hinduism.¹⁴ Aside from the obvious point of this paper centering on self-flagellation with a whip-like device called a discipline, the numeraries of Opus Dei also

partake in wearing the cilice on a daily basis. This small chain-like device has its roots in the hairshirt, which was a “garment made of rough cloth, often woven from goats’ hair or inlaid with barbed chains and worn as [an] undershirt or as [a] girdle in order to inflict discomfort.”¹⁵ Furthermore, members are also obliged to be full participants of corporal mortification, in which not just the physical aspects of self-flagellation and wearing of the cilice apply, but also the mental aspects, which are very much a complementary component to the more carnal commitments. The Catholic Encyclopedia states that corporal mortification is “the deliberate restraint that one places on natural impulses in order to make them increasingly subject to sanctification through obedience to reason illumined by faith.”¹⁶ Countless Catholics, especially ascetics and monastics, have practiced the role of ritualized corporal mortification, but as Simone Weil states, “the extreme greatness of Christianity lies in the fact that it does not seek a supernatural remedy for suffering, but a supernatural use for suffering.”¹⁷ Hence, the very act of the ritual itself, that of participating in the imitatio Christi, or, reliving the suffering and pain that Christ went through while sacrificing himself for our sins, means something very sacred to those who practice such actions. Therefore, the ritual flagellants are, as Mircea Eliade states, “conscious that they are reproducing, to the smallest detail, the paradigmatic acts of the god[s] as they were performed in illo tempore.”¹⁸ It was said of the late Pope John Paul II in his self-participation of self-flagellation that “We would hear it --we were in the next room at Castel Gandolfo. You could hear the sound of the blows when he would flagellate himself. He did it when he was still capable of moving on his own.”¹⁹ This description by a group of Polish nuns confirms the commonality of the act and what Rev. Michael Barrett stated for a CNN article in January of 2010: “This voluntary accepted discomfort is a way of joining oneself to Jesus Christ and the sufferings he voluntarily accepted in order to redeem us from sin.”²⁰ However, are we to believe that the only reason for these self-inflicted acts of pain come from desiring a closer adherence to the divine? As the theorists will point out, there is a purely felt divine and objective reason for doing such an action to oneself, but it is not the only reason. Ritual takes place out of precedence to provide an earnest belief in the teachings of that particular religion or group, and in the case of Opus Dei, the belief in living in closer companionship to God is one of the key elements.

SELF-FLAGELLATION RITUAL

I will describe the ritual of self-flagellation subsequently. The whole purpose of describing such a sacred act is to understand how it is done, in order to elucidate its efficacy, with help from theorists to come later.

Since this particular ritual is not the only one practiced throughout the faith of the Opus Dei group, I will employ careful consideration on the length, duration, and specificities of this ritual. Within the group, every action builds on the next, and self-flagellation is just one of those steps in becoming closer to God. Therefore, we can assimilate the discussion of the ritual itself around many other practices that members of Opus Dei participate in, and the sum total relation of all of them to God and to the theorists’ works.

In the ritual, the person encloses himself in a private room such as a bathroom or a bedroom. The Opus Dei member makes the Sign of the Cross, in order to initiate both the prayer that will be said, as well as the sacrifice of bodily pain for one’s sins. Furthermore, the flagellant removes either the shirt or pants, as the small whip-like device resembling a macramé²¹ is used on the back or buttocks area. Next, the performer starts whipping oneself while simultaneously reciting the Angelic Salutation or the Lord’s Prayer. After this is finished, the person cleans himself of any blood or wounds, dresses in clothing, and ends the prayer with the Sign of the Cross. A real-life description by former member and numerary Agustina López de los Mozos Muñoz is accounted below:

I learned about the “disciplines” after being in the Work for a little more than a year. It is another form of corporal mortification. It is a whip made of cord that ends in little points. It is used on Saturdays, and only on Saturdays. You go into the bathroom, lower your underwear, and on knees, you whip your buttocks during the time it takes to pray a “Salve.” I have to say that I recited the “Salve” at one hundred per hour, because the cracks of the whip on such a painful area leave the skin [in carne viva] for much of the time while you are reciting your prayer.²²

As one can see, the ritual, although not long or extensively harsh on the body, causes quite an impact on the mind and spirit of the persons involved. Therefore, the idea of imitatio Christi, or the reenactment of the suffering of Christ through one’s own actions, and in this case through self-flagellation, is carried out just enough to push the performer in the right direction toward the divine. As observers and theorists, the main set of credentials we must gain from this ritual, as well as the similar one of wearing the cilice for two hours a day, is the idea that “Mortification is, first of all, a means of training the body to endure hardships.”²³ Adding to this statement is the idea that the Catholic Encyclopedia explains in the cleansing of the soul: “Of the diseases it [mortification] sets itself to slay, sin, the one mortal disease of the soul, holds first place.”²⁴ Hence, the mental reasoning for doing such an act is to be granted a clean slate from God concerning the purity of the soul, for “Sin committed it destroys, by impelling to true penitence and to the use of those means of forgiveness and restoration which our Lord has confided to His Church.”²⁵ Furthermore, an Opus Dei numerary in Madrid, Spain, described the purpose of the self-flagellation ritual as a means “To join Christ in his passion, to ask forgiveness for our sins, [and] to gain control over our passions.”²⁶ The main term here is control, which is what the Bible stresses in 2 Peter:

Now for this very reason also, applying all diligence, in your faith supply moral excellence, and in your moral excellence, knowledge, and in your knowledge, self-control, and in your self-control, perseverance, and in your perseverance, godliness, and in your godliness, brotherly kindness, and in your brotherly kindness, love. For if these qualities are yours and are increasing, they render you neither useless nor unfruitful in the true knowledge of our Lord Jesus Christ. For he who lacks these qualities is blind or short-sighted, having forgotten his purification from his former sins.²⁷

This passage perfectly explains what members of Opus Dei are trying to accomplish through corporal mortification in general. ‘Moral excellence’ is key, but it is self-control which solidifies how one interacts with others in the world and how one can interact to

be more like Christ. This is sanctification, the most central tenet that St. Josemaría Escrivá wanted to disseminate throughout the Christian world: the idea that one has to be holy in all forms of life in order to be increasingly aware and to possess the ‘knowledge’ of the divine.

THEORISTS’ APPROACHES

I will now explain how the theories of rites of passage and liminality play a factor within the self-flagellation ritual of members of Opus Dei. Firstly, I will clarify the terms in order to understand them in light of the ritual at hand.

Arnold van Gennep describes rites of passage as a subdivision of three separate but related stages: rites of separation, transition rites, which he coins the liminal stage, and rites of incorporation.²⁸ These three stages set to describe the ritual performer in terms of his departure from a former nature toward the actual transitioning stage, which may involve symbolic meaning and direction, to the readmission to nature and society stage, albeit cleansed anew. However, this idea puts significance in the transitional phase, or the liminal stage, which is mentioned in Victor W. Turner’s book, *The Ritual Process*. Turner regards those who are subject to the liminal stage to be involved in liminality, which he describes as “neither here nor there; they are betwixt and between the positions assigned and arrayed by law, custom, convention, and ceremonial.”²⁹ Therefore, the ritual performer is concentrated within an element that is indistinguishable from all others, and in the case of those involved in the self-flagellation ritual, the stage of the actual whipping process of the body would be this liminal phase of transition. *Limen*, which in Latin means ‘threshold,’ accounts for the ritual performer to be in a state in which only participants are allowed. It is rather closed off, as the sole purpose of the ritual, the self-mortification through whipping, is to communicate penitence for sins and to harbor the passions of life between the performer and God. This ritualized act, however, incorporates cleansing of the body and of the mind, as again, the entire idea of mortification is “that the passions and sensual concupiscences, which when freely indulged exercise so pernicious an influence on human conduct, should be trained by judicious repression to subordinate and confirm their desires to the rule of reason and in faith, as discerned by the mind.”³⁰ Moreover, this rite of purification, just like the monthly mikvah cleansing of menstruating women in Judaism, allows the flagellant to start anew on his journey toward sanctification through work. It is a conversation of sorts, and one that Roy Rappaport describes as “the non-instrumental aspect or component of events that may also include an instrumental component: ‘technique.’”³¹ The “technique” of the ritual, although not too strict, as the numerary member in Madrid states, is formalized and bound. Therefore, the ritual is strict in the sense that each individual who participates in it is doing it rigidly in his own way. This statement ties back in with the idea of sanctification that was touched upon earlier. The individual strives to do his best in what he sees as the proper way to grow closer to Christ and to God. Through the act of whipping oneself, all of the elements of getting down on one’s knees, the taking off of clothes, etc., are performative in the sense that the ritual “serves to express the individual’s status in

the structural system in which he finds himself.”³² The structural system the ritual performer is involved in would have to be not only Opus Dei, but the private devotion to God as well. This is somewhat different from most rituals, in which “the participants transmit information concerning their own current physical, psychic, or sometimes social states to themselves and to other participants.”³³ Furthermore, one must also take into consideration the prayers that are said during the ritualized whipping. Both the Hail Mary and the Our Father convey obedience and intercede on behalf of both the Virgin Mary and God. These powerful prayers, along with the coincidental act of self-flagellation, present a strong effect on the performer. One can almost feel a sense of “awe” when reciting and whipping oneself, which suggests that Rudolf Otto’s ineffable experience of the “numinous” may be in play within the performer.³⁴ Those who experience such strong emotions of all types: guilt for sins, fear of the Almighty, remorse, etc., may not be able to explain where it is that these feelings originate. Theorists such as Rappaport would argue that these feelings are manifested in the ability of performance acting as “not merely a way to express something, but is itself an aspect of that which it is expressing.”³⁵

The three elements of symbolism, purification through liminality, and performance theory allow us to see a different side of the highly questionable ritual, a side that is clearly more explanatory in nature. The ideas presented forth regarding the flagellant and the ritual are very much tied to the Catholic ideals of “good works.” This Christian idealism is therefore prominent in the actual self-flagellation ritual by way of allowing the performer to become a sanctified member of the Church in all aspects of life. Through self-flagellation, he cleanses himself anew, purifies himself of sin, and presents himself to the Lord with the goal of producing an inner self devoid of sin and one involved with the holy. Ariel Glucklich states, “The task of the religious practitioner is often to convert accidental pain or illness (conceived perhaps as punishment) into a positive force acting on behalf of passage, healing, or some other spiritual advantage.”³⁶ This statement ties back into the very first paragraph of this paper, regarding the overall dissatisfaction concerning pain. It is true that leaders and prominent figures of all religions, priests, rabbis, imams, etc., try to rid themselves and their congregations of spiritual pain through divine counsel and prayer. Nevertheless, the above quotation holds true for those that “purposefully” inflict pain on themselves as well. These people, including those who participate in self-flagellation, are looking for a “positive force” that will lead them to a forgiveness of sins and an outlook on life that is full of sanctification through pain-inducing purification.

CONCLUSION

Ritualized pain, although strange to a global worldview convinced on ridding itself of suffering in general, is just another way that many ascetic, religious, and lay people come into a closer relationship with the divine. Throughout this paper, I have argued that the ritual of self-flagellation practiced within the Catholic sect of Opus Dei be analyzed more deeply, in terms of its mental and spiritual implications. By describing the ritual and by providing actual accounts and viewpoints on said ritual, I

have illustrated that the ritual incorporates much more than just the realm of physical pain. Furthermore, I have reached deeper inside the ritual's true meaning by using theories such as rites of purification and performance.

It is through this analysis that I have reached the conclusion that self-flagellation, and corporal mortification in general, has a much deeper impact on the mind than on the body. Through these various rituals, the practitioners receive a will to carry on the Christian ideals that Jesus set forth 2,000 years before, as accounted in the New Testament: "For we are His workmanship, created in Christ Jesus for good works, which God prepared beforehand so that we would walk in them."³⁷ These good works are what Opus Dei members describe as a life full of sanctification. By suffering and controlling themselves through corporal mortification, the participants claim to achieve a clean slate in life, and are thus sent forth to carry this message as well.

NOTES

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Jur e l i g i o n

Computer Modeling of the Cochlea

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When a sound enters the ear, it exerts a pressure against the eardrum, causing it to vibrate. This vibration is then transmitted through bones in the ear to the cochlea. The cochlea is crucial for hearing; it is the part of the ear where the pressure generated from a sound wave is converted into an electric nerve signal that is sent to then the brain. The cochlea can take a wide spectrum of sound waves that vary in amplitude (loudness) and in frequency (pitch), and turn them into signals for the brain. The basilar membrane, which divides the cochlea in half, is displaced due to the excitation at the entrance to the cochlea. The displacement of this membrane is determined by the pressure difference across the membrane. For single frequency excitation, the axial location of the peak membrane displacement amplitude depends on the frequency. Hearing loss usually occurs due to a problem with the hair cells that are deflected by the membrane's displacement. In order to attempt to fix this problem, it is crucial to know how the membrane and the hair cells behave in varying conditions.

The cochlea is spiral in appearance, as shown in the insert of Figure 1. As can be seen in the main diagram of Figure 1, the cochlea consists of three compartments. Each compartment is separated from the others with a membrane between adjacent ones. For purposes of analysis, the Reissner's membrane can be neglected due to its high flexibility. The membrane can also be straightened out. This simplified model is shown in Figure 2. Pressure is applied at the base of the membrane, at the stapes.

The walls of the cochlea are rigid. The cochlea is divided into

two symmetric compartments: the scala tympani and the scala vestibule. Any increase in cross sectional area in one compartment along the membrane will result in the same cross sectional area decrease in the other. Due to this behavior, the excitation of the stapes causes the round window to respond in an equal and opposite way.

A one-dimensional model of the cochlea assumes that the displacement of the cochlea in the vertical direction is a function of the horizontal distance along the cochlea and the time elapsed since the cochlea was disturbed from its rest position, where there is no displacement along the cochlea's length. The analysis of the behavior of this membrane is carried out using the Finite Difference Method to determine the pressure difference across the membrane and the Implicit Euler method to find the basilar membrane's response. The analysis is carried out for the time and frequency domains.

PROCEDURE

Part 1: Overview of Governing Equations of the Cochlea

The analysis method discussed in this report is performed for a one-dimensional model. According to Cohen and Furst (2004), the relationship between the second derivatives of the pressure difference across the basilar membrane ($P(x,t)$) and the displacement of the membrane ($\Delta BM(x,t)$) can be represented by:

$$\frac{\partial^2 P}{\partial x^2} = \frac{2\rho}{H} \frac{\partial^2 \Delta_{BM}}{\partial t^2} \quad (1)$$

where ρ is the density of the perilymph, which is the fluid in the cochlea and H , which is the height of one compartment of the cochlea. The basilar membrane displacement depends on the pressure

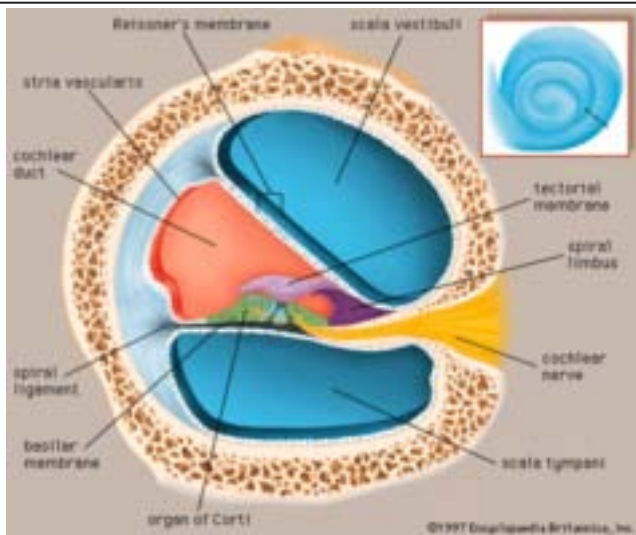


Figure 1: Cross section of the cochlea (Photo from *Encyclopedia Britannica*)

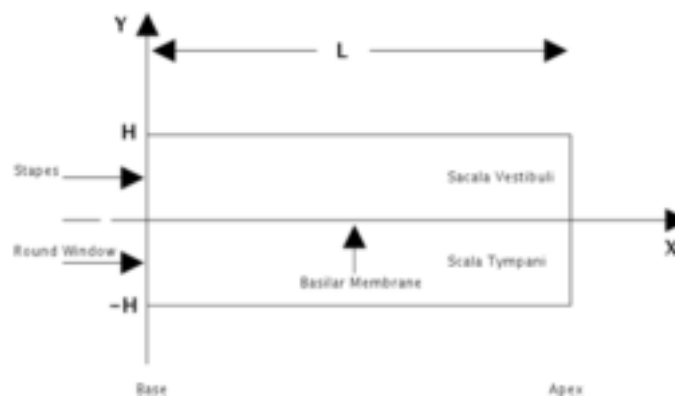


Figure 2: Model of the cochlea unwound (Based on diagram from Neely, *The Journal of the Acoustical Society of America*)

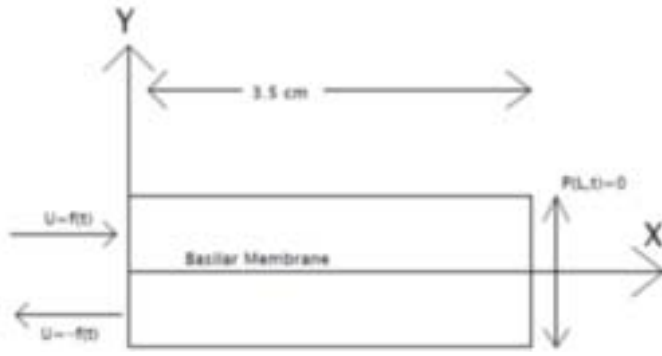


Figure 3: Boundary Conditions of the One Dimensional Model of the Cochlea.

applied to the membrane (PBM) as given in the following equation:

$$P_{BM}(x_k, t_j) = m(x_k) \frac{\partial^2 \Delta_{BM}}{\partial t^2} + r(x_k) \frac{\partial \Delta_{BM}}{\partial t} + s(x_k) \Delta_{BM} \quad (2)$$

where $m(x)$ is the basilar membrane mass per unit area, $r(x)$ is the basilar membrane resistance per unit area, $s(x)$ is the basilar membrane stiffness per unit area, k is the point along the membrane, and i is current time interval. In the simplest model of the cochlea, the pressure difference across the membrane (P) is equal to the pressure applied to the membrane (PBM). This is a passive modeling of the cochlea. The displacement of the basilar membrane can be obtained in two different domains. The first is the time domain, directly using Equations (1) and (2), and the second is the frequency domain, which involves converting Equations (1) and (2) to be functions of input frequency instead of time. Both domains have two steps involved in the analysis. The first is to find the pressure on the membrane and then use that pressure to find the displacement of the membrane.

Part 2: Time Domain Analysis

Solving for the displacements of the basilar membrane requires two boundary conditions of the cochlea and two initial conditions, obtained when the cochlea is at rest.

The first boundary condition comes from the symmetry between the two chambers of the cochlea. The cross sectional area of the tympani and vestibuli are the same at $x=0$. Since the fluid is incompressible, the speed will increase or decrease based on the cross sectional area. At the initial position, the areas are the same, making the velocities equal in magnitude, but moving in opposite directions:

$$U_v(0, t) = -U_t(0, t) = f(t) \quad (3)$$

where U_v is the velocity of the vestibuli, U_t is the velocity of the tympani, and $f(t)$ is the velocity of the stapes. The second boundary condition is at the end of the cochlea. There is a gap at the end where there is no pressure difference:

$$\Delta_{BM}(x, 0) = 0 \quad (4)$$

At time $t=0$, the cochlea is at rest and is not moving, which gives the two initial conditions needed for the time domain

$$P(L, t) = 0 \quad (5)$$

and

$$\frac{\partial \Delta_{BM}}{\partial t}(x, 0) = 0 \quad (6)$$

Equations (1) and (2) can be combined to obtain:

$$\frac{\partial^2 P}{\partial x^2} - \Omega(x_k)P = g(x_k, t_j)\Omega(x_k) \quad (7)$$

where

$$\Omega(x_k) = \frac{2\rho\beta}{m(x)A} \quad (8)$$

and

$$g(x_k, t_j) = -[r(x_k) \frac{\partial \Delta_{BM}}{\partial t} + s(x_k) \Delta_{BM}(x_k, t_j)] \quad (9)$$

The finite difference method is used to approximate the second derivative in Equation (7). The second derivative of the pressure at point k along the membrane can be represented as:

$$\frac{\partial^2 P}{\partial x^2} = \frac{P_{i-1} - 2P_i + P_{i+1}}{h^2} \quad (10)$$

where h is the step size along the membrane in the horizontal direction. Combining Equations (7) and (10) and simplifying, the following pressure relation is obtained:

$$P_{i-1} + (-2 + h^2\Omega(x_k)) P_i + P_{i+1} = h^2 g(x_k, t_j)\Omega(x_k) \quad (11)$$

This relation is valid for all points along the membrane, except for the points at the beginning and the end of the cochlea. The boundary condition at the beginning of the cochlea is used to obtain a relation between the pressure at points $k=0$ and $k=2$, which can then be substituted into Equation (11). As shown in Appendix A, the boundary condition in Equation (3) is used to obtain a rate of change of the pressure:

$$\frac{\partial P}{\partial x}(0, t) = 2\rho f'(t) = \frac{P_2 - P_0}{2h} \quad (12)$$

Solving for P_0 and substituting into Equation (11) gives the pressure relation for the beginning of the cochlea:

$$-\left(1 + \frac{1}{2}h^2\Omega(x_1)\right)P_1 + P_2 = 2h\rho f'(t_j) + \frac{1}{2}h^2 g(x_1, t_j)\Omega(x_1) \quad (13)$$

The second boundary condition, Equation (4), is used for the end of the cochlea. Equations (4), (11), and (13) are grouped together to form A_{const} and B_{const} to be used to solve the matrix equation:

$$[A_{const}] \vec{x} = \vec{B}_{const} \quad (14)$$

where x is the vector of pressures along the cochlea, A_{const} is a matrix formed from the coefficients in front of the pressure terms

and B_{const} is a vector of the constants in equations (4), (11), and (13). Equation 14 represents:

$$\begin{pmatrix} -(1+\gamma^2\alpha_k) & 1 & 0 & \dots & 0 \\ 1 & (-2+\gamma^2\alpha_k) & 1 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & \dots & 0 & (-2+\gamma^2\alpha_k) & 1 \end{pmatrix} \begin{pmatrix} p_k \\ p_{k+1} \\ \vdots \\ p_{k-1} \\ p_k \end{pmatrix} = \begin{pmatrix} \gamma^2\alpha_k(1+\gamma^2\alpha_k) \\ \gamma^2\alpha_k(1+\gamma^2\alpha_k) \\ \vdots \\ \gamma^2\alpha_k(1+\gamma^2\alpha_k) \end{pmatrix} \quad (15)$$

Equation (15) is solved using Gaussian Elimination. This process uses elementary row operations to solve for all of the pressures. The first step in the Gaussian Elimination is to start with the first row and use the on-diagonal elements to eliminate the element that is directly below it in the Aconst matrix. Any operation that occurs in the Aconst matrix must also be done to the Bconst vector. Once all of the below-diagonal elements have been eliminated, an upper triangular matrix remains. Back substitution is then used to solve for the pressures. Back substitution uses the last row to begin solving for the pressure since there is only one element in the row. This element times the pressure is equal to the last entry of the Bconst vector. This pressure can then be solved for and used to solve for the second to last pressure in the row above it, which involves two pressures, one of which is already known. This process is continued until all pressures are solved for.

After the pressures at each point along the membrane have been calculated, the displacements and the rates of displacement for the next time step must be calculated using these pressures. These values are found using the Implicit Euler Method to solve Equation (2), as outlined in Appendix B. The equations for the response of the membrane for the next time step are given by:

$$\Delta_k^{j+1} = \frac{\Delta_k^j(1+\Delta t \frac{r_k}{m_k}) + \Delta t \left(\dot{\Delta}_k^j + \Delta t \frac{p^j}{m_k} \right)}{1 + \Delta t \frac{r_k}{m_k} + (\Delta t)^2 \frac{s_k}{m_k}} \quad (16)$$

and

$$\dot{\Delta}_k^{j+1} = \frac{\left(\Delta_k^j + \Delta t \frac{p^j}{m_k} \right) - \Delta_k^j \left(\Delta t \frac{s_k}{m_k} \right)}{1 + \Delta t \frac{r_k}{m_k} + (\Delta t)^2 \frac{s_k}{m_k}} \quad (17)$$

where t is the time step size.

Part 3: Frequency Domain Solution

The second method to analyze the behavior of the membrane is to use the frequency domain. For this method of solving, there is a frequency applied to the membrane. This frequency causes the displacement of the membrane. When analyzing in the frequency domain, the analysis is carried out at a steady state, meaning that all of the initial transients of the system have died out.

The first step in the analysis is to convert the functions that are dependent on time to functions of the frequency. The pressure, basilar membrane displacement, and acceleration are all functions of time, as are Equations (1) and (2). This conversion is done using

the relationships shown in Equations (18)-(20):

$$p = \bar{p} e^{i\omega t} \quad (18)$$

$$\Delta_{\text{BM}} = \bar{\Delta}_{\text{BM}} e^{i\omega t} \quad (19)$$

and

$$f = \bar{f} e^{i\omega t} \quad (20)$$

Using Equations (18) and (19) and their derivatives, the governing equations can be rewritten as:

$$\frac{\partial^2 \bar{p}}{\partial x^2} = -\omega^2 \frac{2\rho\beta}{A} \bar{\Delta}_{\text{BM}} \quad (21)$$

and

$$\bar{p}(x_k) = [-m(x_k)\omega^2 + ir(x_k)\omega + s(x_k)] \bar{\Delta}_{\text{BM}}(x_k) \quad (22)$$

For the frequency domain, two boundary conditions are needed to solve for the pressures and the membrane displacements. These are obtained by converting the time domain boundary conditions to the frequency domain. The boundary conditions for the frequency domain are:

$$\bar{p}(L, \omega) = 0 \quad (23)$$

and

$$\frac{\partial \bar{p}}{\partial x}(0, \omega) = 2\rho i\omega \bar{f} \quad (24)$$

Solving Equation (22) for the displacement and substituting it into Equation (21), while using the finite difference method to simplify the second derivative of the pressure, gives:

$$\bar{p}_{i-1} + \left[-2 + \frac{2\rho\omega^2 h^2 \gamma(x_k)}{H} \right] \bar{p}_i + \bar{p}_{i+1} = 0 \quad (25)$$

where:

$$\gamma(x_k) = [-m(x_k)\omega^2 + ir(x_k)\omega + s(x_k)]^{-1} \quad (26)$$

Equation (25) is valid for all points along the membrane except for the very first and last points. At the first point, the boundary condition must be applied. Using the finite differences, Equation (24) can be rewritten as:

$$\frac{\bar{p}_2 - \bar{p}_0}{2h} = 2\rho i\omega \bar{f} \quad (27)$$

Combining Equation (27) with (25), the pressure relation for the first point is:

$$\left(-1 + \frac{\rho\omega^2 h^2}{H} \right) \bar{p}_1 + \bar{p}_2 = 2\rho i\omega \bar{f} \quad (28)$$

The boundary condition at the end of the membrane gives the

pressure equation for the last point on the membrane:

$$\bar{P}_n = 0 \quad (29)$$

Equations (25), (27) and (29) are combined to form the matrix equations shown below:

$$\begin{pmatrix} -1 + \frac{2m\omega^2 x_k}{s} & 1 & 0 & \dots & 0 \\ 1 & -2 + \frac{2m\omega^2 x_k}{s} & 1 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & \vdots & 1 & -2 + \frac{2m\omega^2 x_k}{s} & 1 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & \vdots & \vdots & \vdots & -1 + \frac{2m\omega^2 x_k}{s} \end{pmatrix} \begin{pmatrix} \bar{P}_1 \\ \bar{P}_2 \\ \vdots \\ \bar{P}_{n-1} \\ \bar{P}_n \end{pmatrix} = \begin{pmatrix} \frac{2m\omega^2 x_k}{s} \\ \vdots \\ \frac{2m\omega^2 x_k}{s} \end{pmatrix} \quad (30)$$

As in the time domain, Equation (28) is solved using Gaussian Elimination to obtain the average pressures on the membrane. Once these pressures have been obtained, the displacement of the membrane can be calculated using the equation:

$$\bar{\Delta}_{BM}(x_k) = [-m(x_k)\omega^2 + ir(x_k)\omega + s(x_k)]^{-1} \bar{P}(x_k) \quad (31)$$

RESULTS: PARAMETERS USED

The parameters for the system were the same for both the time and frequency domains. The values used are those used by Neely (1981). These parameter values are shown in Table 1.

Four different excitation scenarios are considered: continuous ex-

Parameter	Value
Height (<i>h</i>)	0.10 cm
Length (<i>L</i>)	3.5 cm
Mass (<i>m</i> (<i>x</i>))	0.15 g/cm ³
Resistance (<i>r</i> (<i>x</i>))	200 g/cm ³ s
Stiffness (<i>s</i> (<i>x</i>))	$10^9 e^{-2x} \frac{g}{cm^2 s^2}$

citation, build-up excitation, dual pulse excitation, and impulse excitation.

Case 1: Continuous Excitation

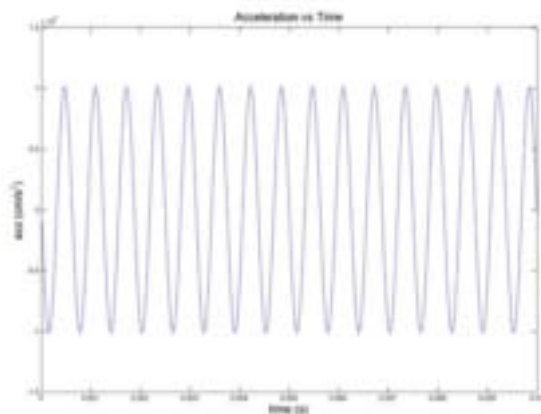


Figure 4: Acceleration as a function of time for the 1600 Hz continuous pulse input.

The first case that is considered is that of a continuous excitation. For this case, the excitation begins immediately at its full amplitude without any gradual build-up. The velocity is applied to the membrane at a rate of:

$$f(t) = 2\pi f_{st} A_{st} \cos 2\pi f_{st} t \quad (32)$$

where A_{st} , the amplitude of the input displacement, is 0.10 cm and f_{st} is the input frequency of the system, in Hz. The velocity is then used to calculate the acceleration of the stapes, a sample of which is shown in Figure 4. The acceleration continues unchanged for the duration of the analysis. The analysis is carried out for a range of input frequencies. Figure 5 shows the displacement of the membrane as a function of time and distance along the membrane at a frequency of 1600 Hz. There are two initial peaks for the displacement of the membrane. Between the first peak and the apex, the displacement of the membrane should be negligible. This model of the membrane suggests that there is an additional transience present. This dies away as the time elapsed increases. As the frequency increases, the time for the transience to die out also increases.

Results Case 2: Build-up Excitation

In the second case, a variation of the sine wave input is applied to the cochlea in order to minimize the presence of the extra transient peak. This input did not start at full amplitude immediately as the continuous sine wave did. This input begins at zero and increases to full amplitude and then, after a number of cycles, decays back to zero, as shown in Figure 6. This velocity of the wave is modeled by the two equations:

$$f(t) = (1 - e^{-\alpha(t-t_{start})}) A_{st} \sin(2\pi f_{st}(t - t_{start})) \quad t_{start} \leq t \leq t_{middle} \quad (33)$$

and

$$f(t) = (1 - e^{-\alpha(t_{stop}-t)}) A_{st} \sin(2\pi f_{st}(t - t_{start})) \quad t_{middle} < t \leq t_{stop} \quad (34)$$

where α is an exponential constant used to control the rates of growth and decay before and after steady state, t is the current time, t_{start} is the time at which the pulse begins to change from zero, t_{stop} is the time at which the pulse has again become zero, and t_{middle} is

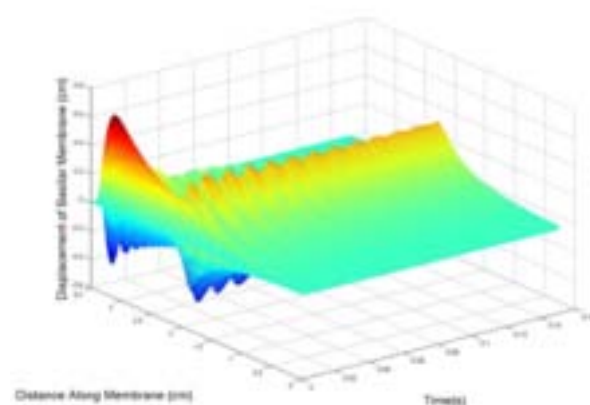


Figure 5: Displacement of the basilar membrane as a function of time elapsed and distance along the membrane.

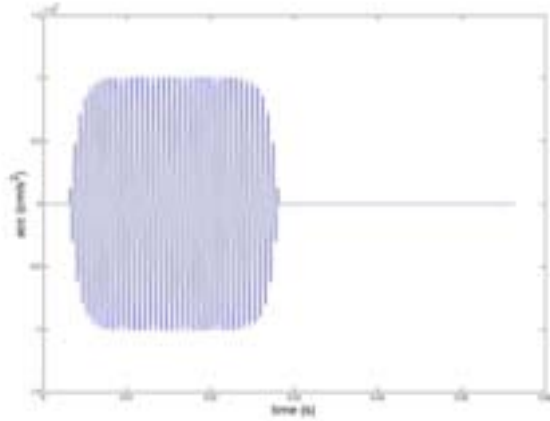


Figure 6: Acceleration as a function of time for the 1600 Hz short pulse.

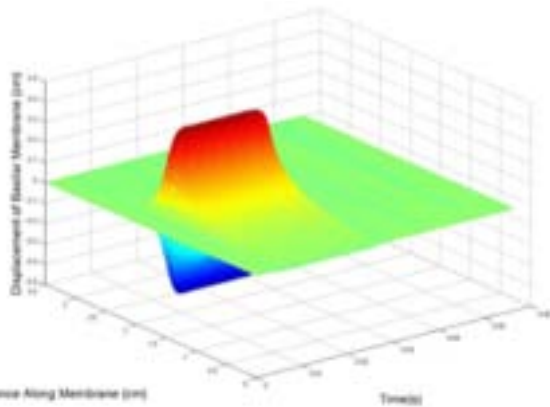


Figure 7: Displacement as a function of distance along the membrane and of time for a short pulse of 1600 Hz.

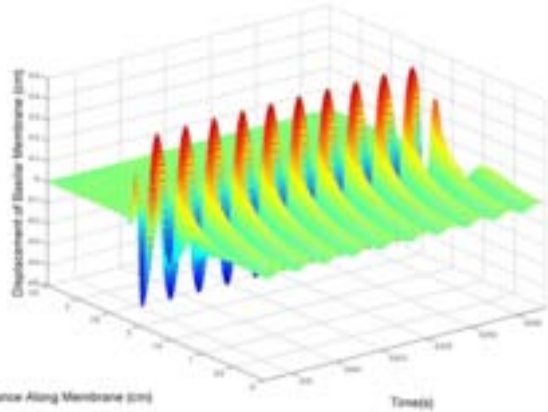


Figure 8: Steady state displacement of the membrane as a function of time and distance along membrane.

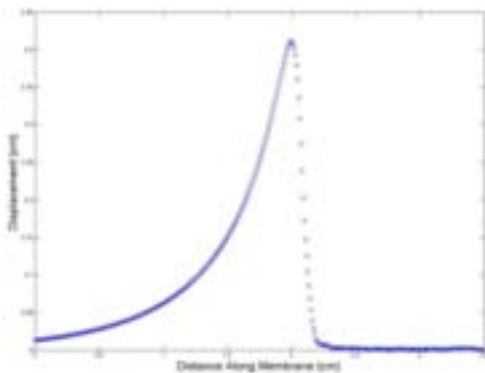


Figure 9: Maximum displacement of membrane for each point along the membrane.

the halfway point between the beginning and the end of the pulse. Figure 7 shows the membrane response for a 1600 Hz input. The pulse shown in the figure has a duration of 30 cycles. The exponential constant for this model is 1000. As shown in Figure 7, there is almost no extra transience in this model. The membrane displacement increases initially and reaches a steady state (shown in Figure 8) and eventually begins to decay back to zero. As Figures 5 and 7 show, the short pulse model of the same amplitude wave is a better model. It is not necessary to carry the analysis out to large time values to obtain a steady state with negligible extra transience. Figure 9 shows the maximum membrane displacement for each point along the membrane at 1600 Hz. At about 2 cm, the magnitude of the displacement is highest. This means that for 2 cm, the resonant frequency is 1600 Hz. Each point has a different resonant frequency, or each different excitation frequency will have the peak displacement at a different point. The displacement of the membrane is negligible between the peak displacement and the apex. This will be true for any frequency excitation sine wave that is applied to the stapes.

Results Case 3: Dual Pulse

A model of the basilar membrane is also analyzed where two short pulses are applied. The second pulse does not start at the same time as the first, as shown in Figure 10. The pulses applied are modeled by Equations (33) and (34) above. The results of this analysis for a first pulse at 1600 Hz and the second pulse at 800 Hz are shown in Figure 11. For the case considered, both pulses last for thirty cycles, the exponential constant (α) for the first pulse is 1000 and for the second is 500. The second pulse begins after the

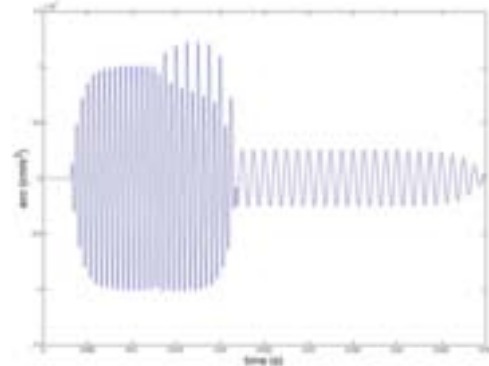


Figure 10: Acceleration as a function of time for the 1600 and 800 Hz pulses.

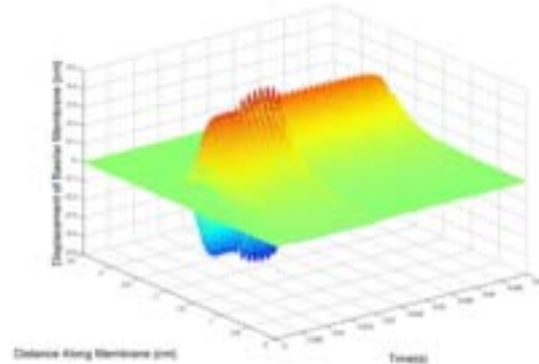


Figure 11: Two pulses applied, one at 1600 Hz and one at 800 Hz. The displacement of the membrane further from the base of the membrane is due to the 800 Hz pulse, while the closer is due to the 1600 Hz.

first has passed the midpoint of its duration. The displacement of the peak of the 1600 Hz pulse increases while the 800 Hz wave is on, but the 800 Hz wave is not affected by the presence of the 1600 Hz. This is due to the behavior of the membrane when a single pulse is applied. After the peak of the single pulse is reached, the displacement almost instantly decays to zero and remains negligible up through the apex, as shown in Figure 9. The peak of the 1600 Hz wave occurs closer to the membrane base than that of the 800 Hz, which means that the 1600 Hz wave would not add any displacement for the 800 Hz wave after its peak. The peak is higher initially for the 1600 Hz displacement due to the additional displacement of the 800 Hz pulse.

Results Case 4: Impulse Excitation

The final model considered for the time domain is the impulse input to the cochlea. For this model, the acceleration is modeled as a short triangular wave, as shown in Figure 12. The impulse acceleration is modeled using the following two equations:

$$f'(t) = \frac{4 \text{ amplitude}}{\text{Period}} t - \frac{4 \text{ amplitude} \times t_{\text{on}}}{\text{Period}} \quad t_{\text{on}} \leq t \leq t_{\text{on}} + \frac{1}{4} \text{ Period} \quad (35)$$

and

$$f'(t) = -\frac{4 \text{ amplitude}}{\text{Period}} t + \frac{4 \text{ amplitude}}{\text{Period}} \left(t_{\text{on}} + \frac{1}{2} \text{ Period} \right) \quad t_{\text{on}} + \frac{1}{4} \text{ Period} < t \leq t_{\text{on}} + \frac{1}{2} \text{ Period}, \quad (36)$$

where t_{on} is the time at which the impulse begins, Period is equal

to the inverse of the frequency, and amplitude is the maximum displacement that results from the impulse. The response of the membrane to this acceleration input is shown in Figure 13. Initially when the impulse is applied, the magnitude is the highest. Without any sustained input, the membrane displacement slowly decays back towards its rest position.

Results: Frequency Domain

The frequency domain analysis is carried out for eleven different input frequencies: 400, 570, 800, 1130, 1600, 2260, 3200, 4520, 6390, and 9040 Hz. Plots of the maximum displacement of the membrane versus location along the membrane are shown in Figure 14. As the frequency increases, the peak shifts towards the base of the membrane and the maximum displacement of the membrane increases in magnitude.

Results: Domain Comparison, Convergence Analysis, and Literature Comparison

The steady state plot of the displacement of the membrane as a function of position should be the same as the plot of displacement versus position for the frequency domain. Figure 15 shows the plot of the membrane displacement for both the time and frequency domains at 1600 Hz. The 1-D time domain results at steady state converges to the frequency domain results. The 1-D results have a lower magnitude peak that is slightly closer to the apex than the 2-D results. This difference could be due to the assumptions that are made in order to create the one-dimensional model.

The convergence of the methods used to solve the system in the time domain are considered to make the running time of the MAT-

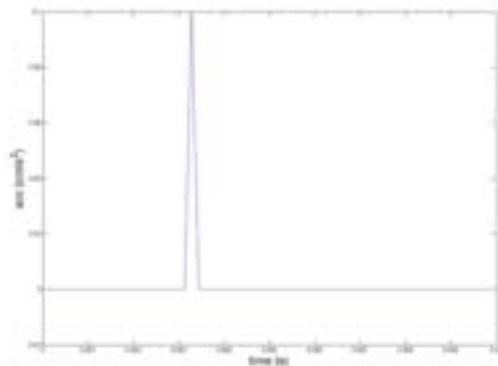


Figure 12: Acceleration as a function of time for the impulse at a frequency of 1600 Hz.

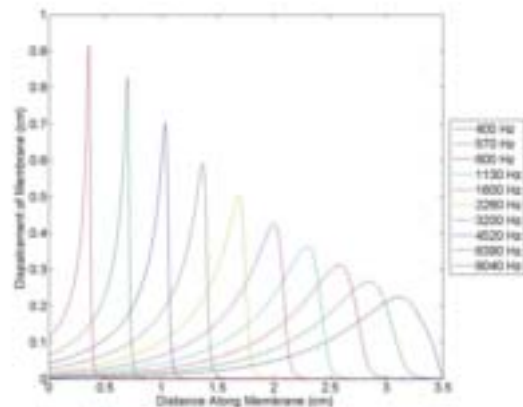


Figure 14: Displacement of the membrane as a function of position along the membrane calculated for various frequencies.

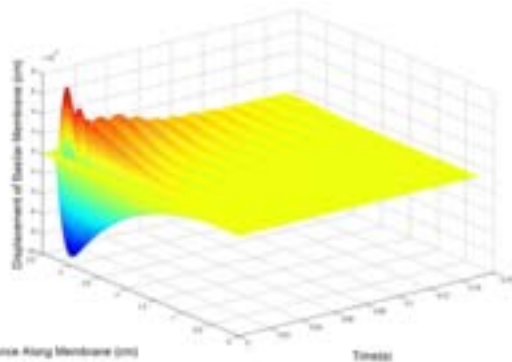


Figure 13: Displacement of the membrane as a function of time and distance along the membrane for an impulse of 1600 Hz.

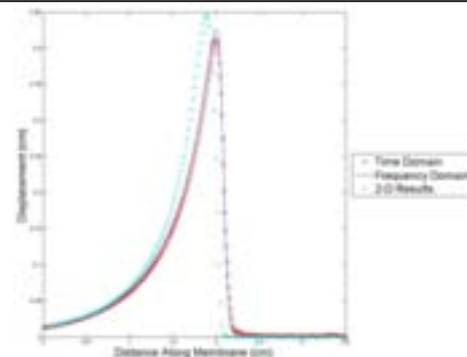


Figure 15: Displacement of membrane as a function of the distance along it. Results shown for the 1-D Time and Frequency domains and the results of a 2-D frequency analysis. The 2-D analysis was done by Yanju Liu of the University of Rochester.

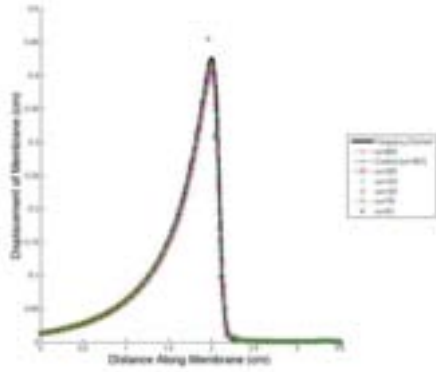


Figure 16: Varying the number of points along membrane while holding the time steps constant.

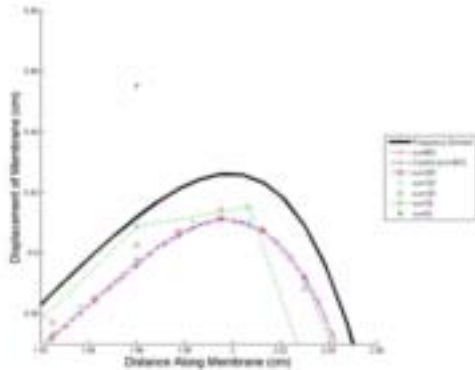


Figure 17: Close up of peak displacement for varying number of points along membrane.

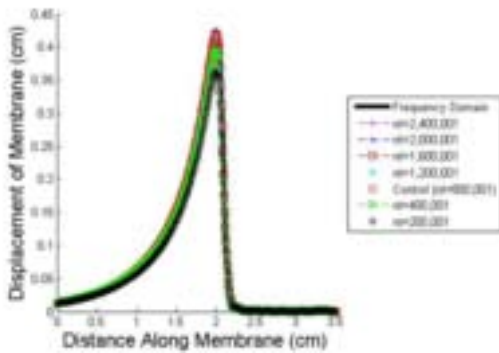


Figure 18: Varying the number of time steps while holding the points along the membrane constant.

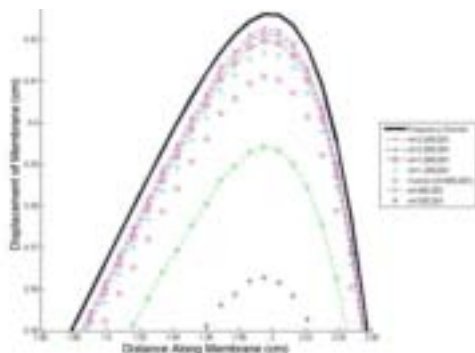


Figure 19: Close up of peak displacement for varying number of time steps.

LAB code as short as possible while still generating acceptable results. This convergence analysis is carried out for the single pulse excitation. The first factor considered is the number of points that the membrane is divided into. The number of points ranged from 51 to 601. The results of the analysis with varying total number of points are shown in Figures 16 and 17. This part of the convergence analysis is done keeping the number of time steps constant at 800,001 and only varying the number of points. As seen in Figure 16, it is hard to see the difference between the results when considering the entire displacement curve. Therefore, it is necessary to consider the portion of the curve where the peak displacement occurs, as shown in Figure 17. Having 201 points along the membrane allowed for sufficient accuracy for the purposes of this analysis.

The second part of the convergence analysis is to determine the optimal number of time steps for the analysis to be carried out at. This is done for time steps totals ranging from 200,001 to 2,400,001, while keeping the number of points along the membrane constant at 401 points. The results of this analysis are shown in Figures 18 and 19. As shown in Figure 18, it is only immediately apparent that 200,001 time steps are not adequate for the analysis. Figure 19 shows that 1,600,001 time steps are about the minimum number of time steps that should be used. Increasing the number of points along the cochlea and increasing the number of time intervals causes the membrane displacement to converge. The frequency domain analysis can be compared to similar figures from previous analysis done with this model. Since the parameters used in this paper are from Neely's experiments, the frequency results are compared to the results from his 1981 paper, shown

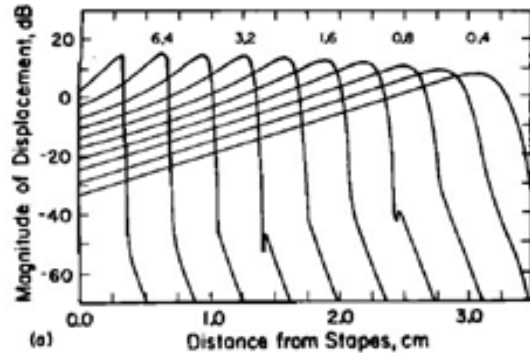


Figure 20: Plot of magnitude of displacement as a function of the position along the membrane for various frequencies with a reference amplitude of 1 cm (Plot from Neely (1981), Journal of the Acoustical Society of America).

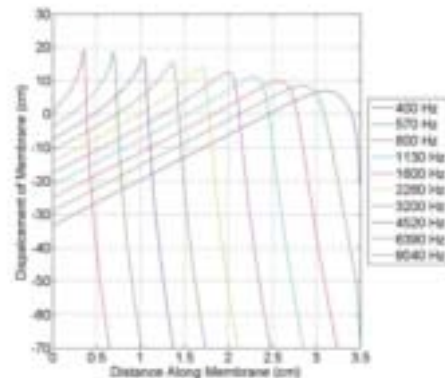


Figure 21: Frequency domain results converted from centimeters to decibels.

in Figure 20. In order to compare the frequency domain results shown in Figure 14, the displacement must be converted from centimeters to decibels. The conversion between the two is given by the equation:

$$L_{dB} = 20 \log_{10} \left(\frac{\Delta_1}{A_0} \right) \quad (37)$$

where L_{dB} is the displacement of the membrane in decibels, A_1 is the membrane displacement in cm, and A_0 is the reference amplitude, 1 cm for this analysis. The frequency analysis must be rerun using the input amplitude (A_{st}) as 1 cm instead of 0.1 cm. The plot of the converted displacements for various frequencies is shown in Figure 21. As can be seen, Figures 20 and 21 are very similar, meaning that the frequency analysis yields roughly the same results as Neely's analysis. The slight variation in location of the peaks is due to assumptions made to make the 1-D model. Since the results of the time domain and the frequency domain for a single sine wave are the same, as seen in Figure 15, the time domain results are also consistent with Neely's work.

CONCLUSIONS AND FUTURE WORK

The membrane behaves differently for different excitations. When a continuous wave excitation is applied, the membrane has a large transience. A single built-up pulse does not have the transience of the continuous wave, but has the same steady state. For dual pulse excitations, the lower frequency displacement adds to the higher frequency displacement of the membrane since the resonant peak of the higher frequency excitation is closer to the base. An impulse causes a large displacement initially and then gradually dies out. For single pulse excitation, the frequency and time domain should have the same displacement curve at steady state.

There are many potential sources for errors. The first is the parameters chosen. Choosing different parameter values will give different results than those obtained in this analysis. A second potential for error is the limitation on how small the time interval can be; any solution will be an approximation of how the membrane responds.

Future work for the 1-D analysis is to use the same technique to analyze the active model of the cochlea, where the pressure difference across the membrane (P) is not equal to the pressure applied to the basilar membrane (PBM).

Appendix A: Conversion of the First Boundary Condition

$$\begin{aligned}
 U_y(0,t) &= -U_x(0,t) = f(t) \\
 \frac{\partial U_y}{\partial t}(0,t) &= -\frac{\partial U_x}{\partial t}(0,t) = f'(t) \\
 \frac{\partial U}{\partial t} &= \frac{\partial U_x}{\partial t} - \frac{\partial U_y}{\partial t} \\
 \frac{\partial P}{\partial x} &= -\rho \frac{\partial U}{\partial t} \\
 \frac{\partial P}{\partial x} &= -\rho \left(\frac{\partial U_x}{\partial t} - \frac{\partial U_y}{\partial t} \right) = -\rho(-f'(t) - f'(t)) \\
 P'(0,t) &= 2\rho f'(t)
 \end{aligned}$$

Appendix B: Derivation of Implicit Euler Equations

$$P_{BME}(x_k, t_j) = m(x_k) \frac{\partial^2 \Delta_{BME}}{\partial t^2} + r(x_k) \frac{\partial \Delta_{BME}}{\partial t} + s(x_k) \Delta_{BME}$$

Rewrite as two equations

$$\frac{d}{dt} \begin{bmatrix} \Delta_k \\ \dot{\Delta}_k \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\frac{s_k}{m_k} & -\frac{r_k}{m_k} \end{bmatrix} \begin{bmatrix} \Delta_k \\ \dot{\Delta}_k \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{P_k^j}{m_k} \end{bmatrix}$$

Using Implicit Method and Finite Differences

$$\begin{bmatrix} \frac{\Delta_k^{j+1} - \Delta_k^j}{\Delta t} \\ \frac{\dot{\Delta}_k^{j+1} - \dot{\Delta}_k^j}{1} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\frac{s_k}{m_k} & -\frac{r_k}{m_k} \end{bmatrix} \begin{bmatrix} \Delta_k^{j+1} \\ \dot{\Delta}_k^{j+1} \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{P_k^j}{m_k} \end{bmatrix}$$

Rewriting and putting grouping terms together

$$\begin{bmatrix} 1 & -\Delta t \frac{r_k}{m_k} \\ \Delta t \frac{s_k}{m_k} & 1 + \Delta t \frac{r_k}{m_k} \end{bmatrix} \begin{bmatrix} \Delta_k^{j+1} \\ \dot{\Delta}_k^{j+1} \end{bmatrix} = \begin{bmatrix} \Delta_k^j \\ \dot{\Delta}_k^j \end{bmatrix} + \begin{bmatrix} 0 \\ \Delta t \frac{P_k^j}{m_k} \end{bmatrix}$$

Let

$$A = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} = \begin{bmatrix} 1 & -\Delta t \frac{r_k}{m_k} \\ \Delta t \frac{s_k}{m_k} & 1 + \Delta t \frac{r_k}{m_k} \end{bmatrix}$$

Use Cramer's Rule to Solve

$$\Delta_k^{j+1} = \frac{\det \begin{bmatrix} B_1 & A_{12} \\ B_2 & A_{22} \end{bmatrix}}{\det(A)}$$

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Midwives as agents of Muhammad Ali's "New Order": Tradition, statehood, and authority in medical understanding of childbirth during the nineteenth century in Egypt

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Based on Muhammad Ali's goals for Egypt's modernization and expansion during the nineteenth century, a large population would be necessary and beneficial (Ali, 2002, p. 24). The stability of Ali's rule allowed for population growth as desired, but the trend of expansion has persisted through to the present day and is now regarded as a problem. Family planning is a priority in the Country Cooperation Strategy for the World Health Organization and Egypt; it is targeted by foreign aid from both US- and UN-supported agencies. Egypt's government today takes a stance opposite to Ali's with regard to population growth; ironically, however, both regimes embody similar attitudes toward dayas (traditional midwives). I will argue that Muhammad Ali's institution of state-trained midwives served to conceptualize advanced scientific methods as capable of manipulating pregnancy and birth. I will discuss how this is a nation-building process and the implications of excluding the dayas in that process. I will also argue that the state-sponsored midwives' training demonstrates cultural transfer of European sensibilities regarding sexuality and conceiving children. I will conclude this analysis of the founding of the School of Midwives by commenting on the legacy of the observed patterns, with attention given both to the changes in women's roles in society and to modern family planning initiatives.

CLOT PROPOSES TRAINING MIDWIVES TO IMPROVE INFANT MORTALITY: CONCEPTUALIZING CHILDBIRTH AS AN EVENT THAT CAN BE PREDICTED AND CONTROLLED

The term *nizam jadid*, which translates to "new order," is often used among scholars to describe Muhammad Ali's transformation of the Egyptian army. The previously-existing notion of military service was completely supplanted. A ragtag assortment of citizen soldiers became a disciplined and uniformed force that could not only defend, but also conquer. Military engagement went from an occasional necessity to a fulltime occupation. Various societal functions that were institutionalized in this way, but Sonbol comments on the unique importance of medicine, because it had implications in the "religious, social and economic affairs of Islamic society" (Sonbol 1991). A systemic overhaul was envisioned for the practice of medicine, and then specifically for

midwifery, by the European doctor who advised Muhammad Ali on medical concerns of the army and of civil society. Muhammad Ali believed in following the advice of experts, and the experts that he consulted were usually European: in the case of medical reform, he particularly consulted Dr. Antoine Barthelme Clot, a Frenchman who had trained at the Hôtel-Dieu Hospital in Marseille and carried doctorates in both medicine and surgery from Montpellier, the oldest medical school in France (Sonbol 1991).

As chief surgeon to Muhammad Ali, Clot was asked to "exert every effort to arrest the disastrous losses" of soldiers due to camp diseases (Kuhnke 1990, p. 32). In connection with this objective, Muhammad Ali realized that "to have a healthy body of troops care had to be given to the general health situation of the population at large" (Fahmy 2002, p. 209). In addition, it was urgent that the general depopulation throughout Egypt be addressed, as Muhammad Ali needed both a military with enough manpower to increase the reach of his jurisdiction as well as a labor pool that would sustain the expansion of agriculture and industry. Clot's solution was to establish the *nizam jadid* in the practice of medicine. According to Clot, the native barber-surgeons (*jarrahs*) had "not a single scientific notion to guide them," and that condescension was perhaps intensified in his attitude toward the traditional midwives (*dayas*). Clot's signature reforms of Egyptian medical education aimed to replace the backward indigenous practitioners with professionals in the image of his own training. He began with general medicine and surgery by founding a Western-style medical school in 1827 (Kuhnke 1990, p. 32). The curriculum emphasized the natural sciences, physiology, and clinical training. The students of Clot's school "wore army uniforms...and were subject to military discipline, the Turks' time-honored punishment of *bastinado*, beating the soles of the feet, sometimes with disabling effect" (Kuhnke 1990, p. 38). Clot argued for distinctive insignia on the army uniforms of his school's students, who graduated to become "senior health officers," as Clot would not allow them to assume the title of "Doctor" (Kuhnke 1990, p. 40). The origins of the Egyptian School of Medicine confirm the priority of Muhammad Ali's army as patients for the school's trainees, but advanced students

were dispatched to different quarters of Cairo during the cholera epidemic of 1831. The disease climate and child mortality rates both demanded that attention be given to the public sector; the general population included potential conscripts and pathogen carriers who came into contact with soldiers. After putting a mechanism into place to produce the European-tailored counterpart of the *jarrah*, Clot turned his attention to the *daya*.

The School of Midwifery also espoused the military tradition of the *nizam jadid*. Clot proposed to produce native midwives in Egypt of the standard of his senior health officers through this school (the Arabic name has alternately been translated as “School of Midwifery” and “School of Maternity”), which he founded in 1832. It was subject to army regulations and was under the jurisdiction of the Ministry of War (Kuhnke 1990, p. 125). Its program of study extended over 6 years including literacy training (Kuhnke 1990, p. 124). This school provides a second example of Clot’s personal legacy for reform, which resulted from his French training but ran counter to the European mainstream. The first example is in the training of the senior health officers; the curriculum neglected the classics in favor of clinical training whereas the typical European physician was a well-to-do gentleman with a traditional humanistic education who believed that “only training in the Greek and Latin classics could fit a young man to undertake medical studies” (Kuhnke 1990, p. 43). The copy of the Hippocratic Oath presented to each graduate of Clot’s school was an Arabic translation (Kuhnke 1990, p. 40). In addition, the movement that urged registration and licensing in the British and French medical profession “included a sustained effort to discredit and exclude midwives as an inferior class of practitioner” (Kuhnke 1990, p. 122). However, there was also “a strong tradition in France of official regulation and instruction for midwives dating back at least to the Bourbon monarchy’s concern about a population decline during 1770s” (Kuhnke 1990, p. 123). A school exclusively for midwifery was founded in Paris in 1793 which offered a yearlong program that attracted women from all over France. Therefore, the heritage of the French medical service and the need for a substitute for the *daya* both determined Clot’s opinion that a School of Midwifery was needed in Egypt.

The significance of the *nizam jadid* in medical education is suggested by Timothy Mitchell’s commentary with regard to the *nizam jadid* throughout Ali’s policies. He notes the continuity between the changes introduced by Ali and those that were engineered by British colonizers approximately half a century later (Mitchell 1991, p. 46). According to Mitchell, the *nizam jadid* produced an effect that he called *enframing*, a “method of dividing up and containing” which created space both neutral and open to government regulation. Being neither personal nor private, neutral space was subject to the involvement and scrutiny of the state. Recognizing that categories of neutral space would break life down into “a series of discrete functions,” the details of personal histories were rendered as data. This provided the scaffolding for statistical analysis of Egyptians by establishing numerical measures on the Western standards of observation; there was no precedent for such scrupulous attention to information about individuals in Egypt, except what had been relevant for taxation. The consequences of this reimagining of space and life will be discussed in three ways relevant to the School of Midwifery: in contrasting the *dayas* with the school-trained midwives, in viewing

pregnancy as a predictable and alterable sequence of events, and in asserting the state’s influence on the sex lives of Egyptians.

EVICTING THE DAYAS’ INFLUENCE: REDEFINING THE FEMALE CITIZEN AND REJECT- ING RURAL RELIGION

In Clot’s original vision, the school-trained midwives were to replace *dayas*; conflict between the two entities and what they represented would be necessary to achieving that goal. To Clot, the *daya* was the “symbol of the whole complex of ‘old-wives’ medicine’ with its magic potions, charms, and incantations, and he did everything in his power to undermine her persistent popularity” (Kuhnke 1990, p. 129). More than 90 percent of deliveries in Egypt were performed by *dayas* until the late nineteenth century, but they were increasingly blamed for infant deaths and unhygienic birthing practices. Clot’s school produced native-born Egyptian women practitioners to replace *dayas*, and this clear attempt to phase out traditional medicine was continued by colonial medical authorities (Ali, 2002, p. 85-86). As a metaphor for the *nizam jadid*, Clot’s action makes clear that Muhammad Ali’s Egypt was to be considered distinctly separate from what it was when he began his rule and that the new Egypt was to be constructed based upon the European standards of approval, so it could also be considered distinctly different from the rest of the Ottoman Empire. The conflict in the co-existence of school-trained midwives and *dayas* manifested in three ways that can be critiqued: in usurping tradition and experience with schooling as grounds for legitimacy and qualification, in contesting traditional respect for the unknown within the human experience, and in standardizing procedures for operation.

The standardization of schools and licensing symbolizes the rendering of education and training as measurable quantities; where the school-trained midwives were literate and up-to-date with Western theories of the human body, the *dayas* were illiterate and never subjected to exams to prove the accumulation of knowledge. Clot and the European colonizers who followed him attempted to substitute measurable knowledge for the traditions that are passed from *daya* to *daya* and from family to family through generations. However, the practitioners with their approval are shown still to lack universal acceptance by the rural Egyptians. Where Clot and the European colonizers blamed *dayas* for the magnitude of the infant mortality rate, evidently, the general population credited the *dayas* for keeping the rate from being higher. One of the differences between the *daya* and the doctor is of social distance; *dayas* are more emotionally supportive whereas professionalism acts as a social isolator in the European tradition (again, European doctors of this time were well-to-do and care of indigent village dwellers might inspire condescension more than humanitarian impulse). The *daya* today takes a defensive stance toward the Western brand of medicine that the state advocates for, based on the experience she builds of successful involvement in births. In an interview with a *daya* published by Kamran Ali, the *daya* describes the actions of a male obstetrician’s intervention in a breech birth “with exaggerated gestures” and says, “I have delivered more than thirty cases like this” (Ali 2002, p. 87-88). The nature of the *daya*’s defensive position demonstrates skepticism for the science espoused by licensed doctors and reaffirms faith and trust in the time-tested

methods that dayas have used for hundreds of years now. To Clot's desired patient population, disease and hardship are not only facts of life, but also "symbolic expressions constructed by 'culture'" (Sholkamy 1980). The persistence of the dayas' role as a faith healer indicates that ideologically, Clot never managed to entirely dissuade the people of the countryside from deeply-rooted alternative concepts of health and illness (Sonbol 1991). The grip of their traditional paradigm may be attributed in part to the influence of Islam-based beliefs.

Treating pregnancy as a predictable and alterable sequence of events would undermine the moral arguments that proliferated through colloquial logic regarding states of well-being. The religious power elite (known collectively as the ulama) viewed this as a challenge to their authority on several fronts. One was in the control of education. Before the creation of schools under Muhammad Ali, "the only teachers in Egypt had been the ulama" (Sonbol 1991). This meant that they had unilateral influence over the "formation of the minds and morals of youth and ranked high in importance and prestige." In direct reproof of the creation of the School of Midwifery, the ulama found their complaints more safely lodged against the graduates than against Clot and Muhammad Ali—they accused the state-trained midwives of being slow, inefficient, and of preventing religious rituals from being properly performed (Sonbol 1991, p. 58). In addition, the removal of girls from the private sphere to attend the School of Midwifery was hardly sanctioned by the ulama or by Egyptian parents (Sonbol 1991, p. 84). This resistance caused Clot extreme difficulty in recruiting the first students for the School of Midwifery; despite the state's willingness to shoulder all the costs of the students' training and upkeep, Clot ultimately obtained Ali's approval to buy slaves for the school to have any students at all. But it was still not popular to consult graduates of the School of Midwifery at times of birth for several years (also in part due to the fear of the unfamiliar, of public exposure, as well as the inability to leave families at home until the last moment), and the government resorted to offering gifts such as clothing for infants in order for the state-trained midwives to have patients. While the preference for the dayas would certainly be one reason for this, there was also resistance to understanding childbirth with standards and common protocols according to Western medicine. Returning to the idea of defining space as designating the container and the contained, the pregnant woman would be a container for the fetus or infant, the contained. According to this perspective, the positive outcome of the pregnancy can be achieved with better results if childbirth is treated as a mechanical and physiological event of extracting contained from container. This paradigm eliminated the mystery that formerly only the dayas and ulama were trusted to interpret; they acted as families' intermediaries with God in forecasting the health of a newborn during the birth. When the daya thought it necessary, she would go to a shaykh (religious scholar) to requisition special prayers (Ali 2002). This would never be expected of a school-trained midwife. The religious hierarchy was understandably opposed to the loss of this foothold in the consciousness of their believers as a consequence of the nationalization of an otherwise family affair. This blurring of boundaries between public and private carried over to the understanding of sexuality as conception's antecedent.

CULTURAL TRANSFER: SITUATING EGYPTIAN WOMEN AS MOTHERS IN THE VICTORIAN FAMILY

According to Mitchell, designating neutral spaces has the power to diminish inaccessibility and invisibility as obstacles to state control; in the context of childbirth, Egyptians' sexuality was thus brought under surveillance (Mitchell 1991). Although the ulama of the time would have preached prohibition of all sexual intercourse outside of marriage between a man and woman, this was not enough to repress prostitution, as it was uniquely tied to the nizam jadid of the military. Muhammad Ali's policy of conscription meant that to an unprecedented degree, traditional family structures were strained by the absence of men for long periods. Wives who were virtually abandoned turned to prostitution as a means of livelihood; as the army traveled, it patronized prostitution locally. Sanctions still existed against public exposure of women as entertainment and gave stimulus to the business of khawwals, or male dancers (Marsot 1984).

The mindset of Clot and the European colonizers was aligned with that of the ulama on these issues, and Clot asserted the agency of the state-trained midwives to mitigate them. As the women over whom Clot had the most control, the students of the School of Midwifery were the immediate target of that agenda. In Clot's desperation to recruit students, he simultaneously satisfied two objectives and offered midwifery as an alternative livelihood to prostitutes (Fahmy 2002). Women were not allowed to leave the school of midwives before they were married, and marriages were arranged to male health officers "to enable both of them to practice their sciences together" (Kuhnke 1990, p. 126). In addition, for any women who were declared missing by their families and then were found and returned to their families by the state authorities, Clot directed his midwives to check their virginity (Fahmy 2002). This represents an utterly novel means of monitoring civilians' sexuality.

A parallel can be drawn between the state's attempts to regulate the sexual lives of its citizens during the nineteenth century and today. The actions of the school-trained midwives, as directed by Clot, served to reinforce the Victorian conceptualization of sexual activity as a necessity for childbirth but subject to strict discipline in all other respects. As part of a nationalist project, the state-trained midwives answered to the state, and it followed that childbirth and motherhood became responsibilities to the state as well. The insistence on discipline and responsibility in determining the care of mothers in childbirth implied a stake in the future of the nation as a new generation of citizens (and potential conscripts) was coming into being. This theme of responsible motherhood prevails through the development of Egyptian identity, as it has continued to present day and is described amply in the writings of Qasim Amin and Rifa'a Rafi' al-Tahtawi, who had great influence as nationalists in the late nineteenth and early twentieth centuries (Mitchell 1991). The difference for modern Egyptian mothers is that the government encourages birth control in addition to consultation of licensed doctors over dayas. Both Ali's initiation of government regulation in what was previously the dayas' exclusive domain and the government's advocacy of birth control represent the reimagining of birth and pregnancy as events with discrete consequences that concern the state.

CONCLUSION

With Muhammad Ali's sponsorship, Clot set in motion a process of reorganizing women's healing and birthing practices to displace dayas with modern medicine. Although the dayas' presence has not been eliminated, it is now limited to rural Egypt, which is more removed from the processes of nationalization, modernization, and globalization that have impacted the cities. This paper has crystallized three objectives on the part of Antoine Clot that were in some way satisfied by his founding of the School of Midwifery, stemming from his blame of dayas for the high infant mortality rates in Egypt when Ali came to power: conceptualizing pregnancy and birth as events with aspects that can be controlled by humans according to modern science, rather than being left to God, creating a signature of Muhammad Ali on Egypt in the arena of medical reform which rejected the dayas and what they represented, and supporting the paradigm of Victorian motherhood with discipline of sexuality and conceptualization of motherhood as a patriotic duty. This discussion can be concluded with a few comments on the School of Midwifery's legacy for the medical profession and public health in Egypt.

The process of establishing *nizam jadid* paved the way for European colonization, but also gave rise to the nationalist notion of Egypt. At the time Muhammad Ali came to govern Egypt, it was a province of the Ottoman Empire; when his rule ended, it was on its way to fitting the modern definition of a nation-state. Obedience to the policies of Ali and Clot was not voluntary, but the people were conscious in following them and engaged them with their hearts and minds. The School of Midwifery was a unique contribution to the Egyptian nationalist process in two important ways: it enfranchised women in Ali's bureaucracy and in the medical profession that was to be recognized internationally thereafter, and it supplemented the growth of the young public health system, which had never before existed in such an organized manner. The school-trained midwives were part of Muhammad Ali's programs of disease control for cholera and of vaccination for smallpox, and served in various other medical capacities such as in the conduction of autopsies. Putting women in this role and defining that role in a secular, European-influenced framework induced competition between the state and *ulama* which would feel very familiar in the colonial encounter, but would also put Egypt in a different position than any other part of the Ottoman Empire after that encounter. Marsot describes that position as having prepared Egyptian women to cast off the shackles of patriarchy much earlier than women in other parts of the Middle East (Marsot 1984).

It is difficult to clearly correlate the involvement of the state-trained midwives with any decrease in infant mortality, but the phenomenon of depopulation was reversed within Ali's rule. At the beginning of the nineteenth century, Egypt's population was less than 3 million; it was near 10 million by the end (Sonbol 1991, p. 57). As overpopulation has taken the place of depopulation as the state's concern, the state's involvement in pregnancy and childbirth is just as important now as it was in the nineteenth century, and the conflict between the state and traditional ideologies continues from where it started with the introduction of the School of Midwifery.

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Electromyographic Responses to Rotational and Translational Perturbations

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Electromyographic (EMG) responses of lower leg muscles to postural perturbations during standing were studied to determine the effect of perturbation type and prior knowledge on the timing and response profile of muscle activation. We hypothesized that onset latencies and variances of EMG signals from the tibialis anterior (TA) and soleus (SOL) would be affected by 1) the type of perturbation and 2) prior knowledge of the perturbation type presented. The dependent measures were EMG onset delay from perturbation, EMG magnitude, and occurrence of silent periods. Five young, healthy adults received toes-up rotation and posterior translation underfoot perturbations via a dynamic posturography platform. Perturbations were presented on three different days in blocks of sixteen trials. The first two blocks contained rotation and translation trials, respectively, and the third block contained a randomized mixture of rotation and translation trials. The results demonstrated that prior knowledge had no effect on the presence of silent periods. However, silent periods occurred more frequently in the TA for rotation trials than for translation trials. There was a significant perturbation effect on TA onset latencies and TA and SOL variances, as well as a significant block and perturbation interaction effect on the SOL variances. From these results, it appears that postural responses to rotation and translation perturbations are controlled by different motor programs, which, in turn, are modulated by prior knowledge, varying the onset magnitude of certain muscles.

INTRODUCTION

Falls are one of the most common causes of injury in the elderly.⁹ In 2000, 10,300 fatal falls and 2.6 million medically treated non-fatal fall-related injuries were reported.¹⁷ Consequently, much of today's research is devoted to developing interventions to prevent falling. For example, studies have shown that performing balance exercises regularly decreases the likelihood of falling,⁸ suggesting that standing balance directly correlates with falling. Thus, to develop better falling interventions, it is necessary to better understand the human motor control system.

Silent periods have loosely been defined as cessations of

activity preceding elevated EMG levels.¹ Staude et al. (2000), however, define silent periods more exactly, stating that "a segment is considered a silent period if the variance of the corresponding cluster is smaller than those of the two adjacent segments and if the variance of its predecessor is smaller than the variance of its successor".¹⁶ Silent periods in ballistic action have been shown to be associated with the reinforcement of force and an increased motor unit synchrony prior to rapid movement.¹⁴ Few studies, however, have explored how silent periods affect the short loop stretch responses and long loop voluntary responses that are often found within elevated EMG levels.¹⁴ The effect of silent periods on EMG responses to postural perturbations has not been thoroughly investigated either. The minimal discussion of silent periods in the literature could be due to that fact that EMG responses to postural perturbations are typically averaged across many trials, masking the silent periods present in individual signals.^{6,7,10,11,12,13} Additionally, silent periods may have short durations and are hard to detect.¹⁴ However, new methods have been suggested for detecting silent period, as well as the onsets of other muscle activation levels.^{5,15}

In previous studies the effect of sensory confusion on the stereotypical pattern has been explored. Specifically, studies have compared responses to toes-up rotation and posterior translation. These postural perturbations are designed to elicit similar stretch responses in the subject's ankle plantarflexors, but require opposite motor responses to maintain balance. In the toes-up rotation case, large responses in the ankle dorsiflexors are needed to pull the body's center of mass forward to regain balance. In the posterior translation case, on the other hand, the body's center of mass must move backward to maintain balance. As a result, a large response is needed in the plantarflexor muscles. It has been suggested that responses to these sensory confusing perturbations can be affected by previous experience. For example, Chong et al. have shown that a person's ability to respond appropriately to a rotation is decreased after experiencing a series of translations.³ Appropriate response rates also decreased when translations and rotations were alternated.³ However, neither the timing of the perturbations

nor the order in which they occurred was randomized in Chong et al.'s study. Thus the subject always had some degree of prior knowledge. A study conducted by Mummel et al. used the same perturbation types to look into the absence of prior knowledge by comparing the magnitude of EMG responses for "expected" and "unexpected" trials.¹⁰ However, differences in EMG onset latencies for expected versus unexpected trials were not discussed.¹⁰ The purpose of this study is to determine the effect of perturbation type (toes-up rotation or posterior translation) and prior knowledge on the timing and response profile of muscle activation.

METHODS

Data Collection

Five young, healthy adults between the ages of 18 and 30 years (average age = 24.2, standard deviation = 1.64) were recruited. They were screened to ensure they were free of musculoskeletal, neurologic, and vestibular disease at the Eye and Ear Institute (University of Pittsburgh Medical Center, Pittsburgh, PA) as part of a larger study. Testing occurred over three separate days with a minimum of 24 hours between each testing session. The first testing day was preceded by a screening day, during which the subjects were given the opportunity to become familiar with the postural perturbations to be tested. The perturbations included a rapid toes-up rotation of 3.4 degrees and a posterior translation of 4 cm. The rotations and translations were generated as sigmoidal profiles with maximum velocities of 18 deg/s and 24 cm/s respectively. The perturbation types were designed to elicit similar stretch responses in the subject's ankle plantarflexors while requiring opposite motor responses to maintain balance.

On each testing day, subjects performed three blocks of sixteen trials. The first block contained sixteen rotation trials, the second block contained sixteen translation trials, and the third block contained eight rotation trials and eight translation trials for each testing session. For the first two blocks, subjects were informed of the perturbation type (rotation or translation). For the third block, subjects were told that both perturbation types would be present, but they were not informed of the order in which they would occur.

During the experiment, subjects stood on a dynamic posturography platform (NeuroCom, Inc., Clackamas, OR) with their ankles in line with the axis of rotation as displayed in

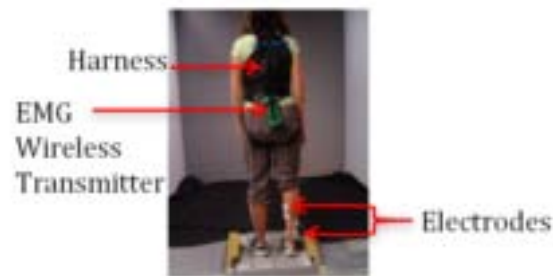


Fig 1: Experimental setup. Subject standing on dynamic posturography platform with electrodes placed on the tibialis anterior, gastrocnemius, and soleus muscles of the dominant leg.

Figure 1. They wore a harness to prevent ground contact injuries in the event of a fall. EMG signals were collected via surface electrodes placed on the tibialis anterior (TA), gastrocnemius (GAS), and soleus (SOL) muscles of the subject's dominant leg (TeleMyo 900; Noraxon, Scottsdale, AZ). Data was collected using LabVIEW (National Instruments, Austin, TX) and analyzed in MATLAB (MathWorks, Natick, MA) to locate silent periods and determine EMG latencies. Due to limited power, only the TA and SOL muscles were analyzed here.

Data Processing

To locate the silent period(s) and the onset of EMG responses, a sequential change point detection algorithm, modified from Staude et al., was used.¹⁶ In the current study, the whitening filter suggested by Staude et al. (2000) was omitted because it tended to eliminate silent periods from the data when baseline activity was minimal. The resulting algorithm was then a two-step process: first, a sequential two window approximated generalized likelihood ratio (AGLR) test is applied to the EMG signal to determine where changes in the signal's variance occur, and second, a post-processor uses an F-test to group parts of the signal with similar variances into classes, which loosely represent different levels of muscle activation.

In the AGLR step, a fixed window slides over the EMG signal while a second, growing window increases in length until a potential change point is reached. Change points are detected at the beginning of the growing window, and after each change point is identified, the windows reset so that the growing window begins at the detected change point. This process repeats for the duration of the signal, resulting in several change times, which effectively divide the signal into segments. Potential change times are computed using the log-likelihood ratio test function,

$$g(k) = -\frac{1}{2} \left[(k-L-t_{m-1}) \ln(\hat{\theta}_k) + L \ln(\hat{\theta}_k) - (k-t_{m-1}) \ln(\hat{\theta}_{k-L}) \right] \quad (1)$$

where k is the current time point of the leading edge of the fixed window, L is the fixed window length, t_{m-1} is the previously identified change time, $\hat{\theta}_k$ is the signal's variance within the growing window (before $k-L$), $\hat{\theta}_{k-L}$ is the signal's variance within the fixed window (after $k-L$), $\hat{\theta}_k$ and $\hat{\theta}_{k-L}$ is the variance of both windows combined. A potential change time is triggered when the log-likelihood ratio exceeds a set threshold h .¹⁶ After a potential change time is triggered, a more exact change time is found by maximizing the likelihood function between the previous change time plus L and the current potential change time,

$$\Lambda(j) = -\frac{1}{2} \left[(j-t_{m-1}) \ln(\hat{\theta}_j) + (t_m + \Delta - j) \ln(\hat{\theta}_j) \right] \quad (2)$$

where j is the current estimated change time, t_{m-1} is the previously identified change time, Δ is the minimum number of points reserved to calculate the variance of the signal after the current change time, $\hat{\theta}_j$ and $\hat{\theta}_{t_m + \Delta - j}$ are the signal's variance before and after the current change time, respectively, and t_m is the first time after the previous change time at which $g(k)$ exceeds h .¹⁶ For the current

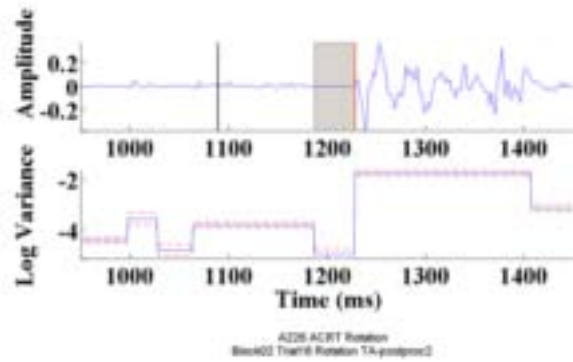


Figure 2: Typical TA results from a rotation block. Plot A shows an analyzed EMG signal annotated with the start of the platform motion (black line), a silent period (gray shaded region), and the onset of EMG activation (red line). Plot B illustrates the estimated variance profile of the analyzed EMG signal with 95% confidence interval (red dashed line).

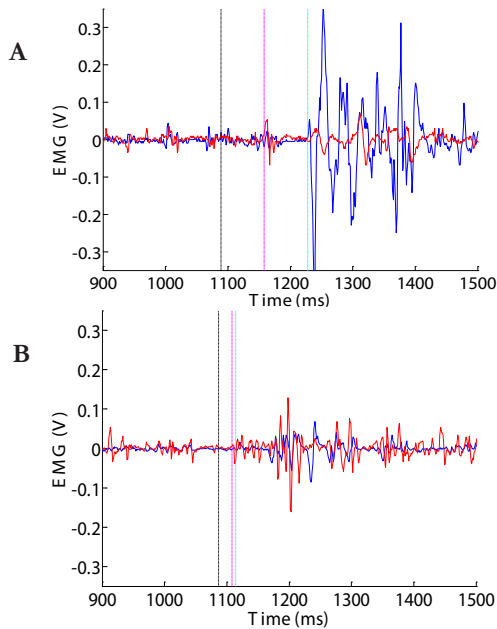


Figure 3: EMG onsets for TA and SOL in A: a rotation trial and B: a translation trial. The solid blue and red lines indicate the recorded TA and SOL responses, respectively. The dashed black, blue, and red lines indicate the onsets of platform motion, TA and SOL, respectively.

Table 1: ANOVA for EMG Onset Latencies and Variances

Effect	p-values			
	TA Lat.	TA Var.	SOL Lat.	SOL Var.
Day	0.201	0.553	0.836	0.364
Block	0.498	0.732	0.241	0.115
Day*Block	0.946	0.821	0.900	0.902
Pert	0.024*	0.005*	0.183	0.015*
Day*Pert	0.506	0.449	0.913	0.626
Block*Pert	0.495	0.743	0.269	0.002*
Day*Block*Pert	0.806	0.607	0.919	0.549

* indicates significance ($\alpha = 0.05$); "Pert" stands for perturbation

Table 2: Silent Period Occurrence (mean \pm std)

Pert. Type	Muscle	Block Type	
		Single	Mixed
R	TA	31.3% \pm 20.6%	37.5% \pm 22.2%
	SOL	27.1% \pm 7.93%	25.8% \pm 8.01%
T	TA	14.2% \pm 11.8%	16.7% \pm 19.1%
	SOL	27.1% \pm 7.93%	30.8% \pm 18.8%

"Pert" stands for perturbation

study, the length of the sliding window, L , was set to 30 points, the threshold, h , was set to 10, and Δ was set to 10.

In the post-processing step, the variance was computed for each segment between successive change times. High variance segments were alternated with low variance segments until all variance values were interleaved. An F-statistic was then used to compare the ordered variances to class levels based on a significance level of α . As each segment was added to a class, the class variance was updated to include the new value as detailed in Staude et al.¹⁶ Following the class assignments, if adjacent segments within the original signal fell into the same activation level, they were merged together, and the potential change time between them was eliminated.¹⁶ In the current study, the significance level for the F-test was set to a value of $\alpha = 0.001$ for SOL and $\alpha = 1 \times 10^{-11}$ for TA. A lower significance level was used for TA due to an increased signal to noise ratio.

After the raw EMG signal passed through both steps of the change point algorithm, the EMG onset, onset variance, and presence of silent periods were found for both the SOL and TA signals. The EMG onset was identified using two criteria: first, it must occur at least 20 milliseconds after the onset of platform motion, and second, it corresponds to the first increase in variance that is greater than the minimum variance of the trial plus 1% of the trial's variance range. The silent periods were identified as defined by Staude et al. (2000; see introduction) within the first 300 milliseconds following the start of the platform motion.

Statistical Analysis

A three-way repeated measures ANOVA was performed on all EMG dependent variables. The independent variables were day (1, 2, or 3), block type (single or mixed), and perturbation type (rotation or translation). Dependent variables were the EMG median latencies and variances for the TA and SOL. Silent periods were analyzed by percent occurrence within block and perturbation type and averaged across subjects.

RESULTS

Overall, the change point algorithm, combined with the EMG onset identification criteria, identified the EMG onsets and silent periods fairly accurately, as indicated by Figures 2 and 3.

For TA, the variances at the onset were larger and the latencies were longer in rotation trials than in translation trials, with across-subject mean latencies and standard errors of 132.8 ± 12.5 ms and 83.6 ± 12.5 ms, respectively. SOL latencies followed the same trend, but were not significantly different between perturbation types, with across-subject mean latencies and standard errors of 98.9 ± 14.5 ms for rotation trials and 68.2 ± 14.5 ms for translation trials. SOL variance values, however, were larger for translation than rotation trials. In addition, they were larger for translation trials in the unknown condition versus the known condition.

Table 1 displays the p-values for the median EMG onset latencies and variances for both the tibialis anterior and the soleus. As expected in the trends detailed above, a significant perturbation effect was found for the median variances of both muscles, as well as for the median onset of TA. In addition, a significant block and perturbation interaction effect was found

for the median variances of SOL.

Table 2 demonstrates that the across-subject mean percent of trials in which a silent period occurred was about twice as large for TA single rotation than for TA single translation. Similarly, the percent of TA mixed rotation trials with silent periods was approximately double the percent of TA mixed translation trials with silent periods. Percentages were approximately the same across-block type and perturbation type for SOL.

DISCUSSION

As suggested previously in the literature, perturbation type and prior knowledge are believed to have an effect on motor responses to postural perturbations.^{3,5} Table 1 reveals significant perturbation effects for the variances of TA and SOL and the latencies of TA. However, prior knowledge only affected SOL variances of translation trials. No prior knowledge effect was seen for rotation trials, despite the greater potential for cortical input derived from their longer latencies.¹¹ Additional support for the lack of significant effects in the EMG latencies comes from Thigpen's belief that the timing of response to postural perturbations "depend[s] upon intact peripheral triggering mechanisms" or spinal cord processes.¹⁸

Silent periods also lacked a prior knowledge effect. Table 2 shows no indication of differences between the known and unknown conditions of either perturbation type. The perturbation type effect, however, may be present. Comparing the percent of trials in which a silent period occurred for TA rotation and TA translation suggests that silent periods occur more frequently in rotation trials than in translation trials for the TA muscle. Since more force in the TA response is needed to stabilize one's position after rotation perturbations and less force is required in the TA response after translation perturbations,³ the TA results support Aoki's suggestion that silent periods enhance the force of the initial EMG response.¹ The absence of a perturbation effect in the SOL muscle could be due to the fact that the SOL tends to respond to perturbations with an early stretch reflex.² This stretch reflex is generated by a spinal cord process and is initiated much sooner after a perturbation than the voluntary reflexes from cortical processes.

One limitation in this study is the small population size. Additionally, the study only considers whether or not a silent period occurs in a given EMG response, not the number of silent periods that occur or their duration. Overall, more data is required to verify the results obtained in this study and to determine if the number or duration of silent periods affects EMG onset latencies for different postural perturbations. In the future, the EMG responses obtained from the young adults in this study will be compared to EMG responses to postural perturbations from elderly subjects, which will provide greater depth and credibility to our results.

CONCLUSIONS

This study revealed that there is a significant perturbation effect on tibialis anterior onset latencies and tibialis anterior and soleus variance. A significant block and perturbation interaction effect on SOL variance was also found, and silent periods tended to occur more frequently for TA rotation than for TA translation. Overall, the results of this study are not strong

enough by themselves to yield definitive conclusions regarding the effect of perturbation type and prior knowledge on the timing and response profile of muscle activation. However, further study of the questions posed here in larger and more varied populations may lead to a better understanding of the human motor control system.

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Trade and why it makes us uncomfortable: Addressing some common concerns in embracing free trade

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According to a poll conducted by the Pew Research Center in April of 2009, only 44% of Americans openly support free trade. What about the other 56%? In this paper, I explore sociological reasons for why people are hesitant to embrace free trade. Why do people have such perceptions of the costs of free trade?

1. INTRODUCTION

I grew up in a household where my father was very interested in politics and economics; my brother followed in his footsteps and is now pursuing a Ph.D. in economics. My whole life I was told that everyone unquestionably benefits from voluntary trade and that trade can be viewed as one of the primary ways by which people increase their happiness. It might sound strange to view trade as such a central component of the economy, but I think of free trade as simply any voluntary, peaceful agreement between two or more entities. In this sense, almost any social interaction is a trade. When I get together with my friends, I am trading the enjoyment of my company in exchange for the enjoyment of their company. When I travel to a new country, I am trading with individuals in the country I am visiting; I trade my money for the ability to see their country, to eat there, to stay overnight there, etc.

Since I grew up learning about the mutually beneficial nature of trade, I was surprised when I came to college only to discover that many of my peers think about trade differently. They view trade as a direct exchange of goods and services, where money is almost always involved. There are significant barriers to their acceptance of free trade, and these barriers span many different categories. Some believe that these barriers ought to intervene in sovereign choices; many think that we ought to give preferential treatment to trading with developing countries and that we must make sure this trade occurs at a fair price. Some think that we ought to look out first for our fellow Americans before trading with people in other countries. Several others believe that voluntary trade can be coercive, especially if one party benefits more than another party. The people of this school of thought simply have too narrow a definition of trade, and don't realize that almost anything involving more than one person is a trade.

Having grown up learning the benefits of free trade from my family and from my economics classes, I became strongly interested in reading about what the "other side" has to say. I had never researched arguments for protectionism, buy-local, or any of the other movements I will discuss; I think that studying these ideas can help me solidify my own ideas about trade. Regardless of whether or not I agree with the barriers people have in accepting trade, it is obvious that trade is too costly for some people. For this reason, I will attempt to approach my analysis of this topic in an objective way and make as factual and accurate a cost benefit assessment as possible. Preferences can often be meddlesome and not essential to economic analysis, so a proper treatment and understanding of these preferences could prove enlightening. I will attempt to determine how consistent people are in these preferences, and evaluate whether or not we should do anything about it.

My aim is to explore how people think, or where people draw the line on free trade. By approaching this question from a sociological and psychological standpoint, I will be able to evaluate whether or not these behaviors can be viewed as "rational" from an economic standpoint. I think a lot of the problems people have with trade boil down to a perception of impersonality. People do not know much about who is involved in the process of consuming and producing goods. This can be a source of discomfort for many people. There are a few reasons for this discomfort that I would like to explore, ranging from concerns over the ethicality of the way their goods are produced to the aversion to, or misunderstanding of, other races and cultures.

Another issue people might have with trade is that few people are producing goods for self-consumption. Some argue that if the people who produce goods do not consume them, then the producers might have less of an incentive to make the best product possible and would instead opt for the cheapest production possible.

Another cause of discomfort about trade is that, since the production of one good involves the input of many different people, no one in the end knows how to make the good in its entirety. People are fearful of the dependence that trade creates;

they tend to value production that aims at self-reliance. They also do not realize that this dependence on one another, and even that trade itself, is not necessarily a bad thing. It is human nature to trade: there is no danger of it collapsing beneath our feet.

Lastly, people might not even realize what the scope of free trade is. After all, is not any social interaction a form of trade? Thinking of trade only in terms of money, or the direct exchange of goods and services, might color our perception of trade in a biased way.

I will discuss some popular trade movements in a targeted way. The reasons I give for why people subscribe to these movements are tailored to the subject of my paper, and I recognize that there are reasons for why people participate in these movements for which I cannot comment on.

2. HOW HAS TRADE EVOLVED? ARE ETHICS IMPORTANT IN TRADE?

“Commerce is the name for free, mutual, and voluntary exchange among peoples. It is the normal activity by which interdependence is realized and the common good for all served. It is an activity typically more unifying than politics, nationalist, religion, or conquest. Its nature is social, as is its function, and as are the virtues it inculcates.” – Michael Novak, 1989

In *The Rational Optimist*, Matt Ridley takes the reader through a survey of human history and shows how trade has always been at the center of its progress. He explains that progress is the direct result of exchange and specialization, and everybody working for the common good. He argues that the resulting codependence is beautiful, amazing, and a source of hope, not despair. Ridley manages to invert the feelings most people have about capitalism and modernism from lamentation to praise.

In *The Bourgeois Virtues*, Deidre McCloskey explains how lives centered on trade do not have to be devoid of ethics. McCloskey argues that you can be virtuous and supportive of trade, and that markets can actually improve ethics while also making us richer. She argues that the “greediness” people associate with capitalism is not the result of a recent change for the worse in manufacturing, but that humans have always felt the need to be greedy. This desire is even mentioned as early as 29 BCE in *The Aeneid*. These historical examples demonstrate that we can concurrently be “commercial” and virtuous. McCloskey lists seven commonly cited Western virtues. She shows how the market inculcates people with every single one of these virtues. Take justice, for example. “A third [virtue] is the Justice to insist on private property honestly acquired. But it is also the justice to pay willingly for good work, to honor labor, to break down privilege, to value people for what they can do rather than for who they are, to view success without envy, making capitalism work since 1776.”

Ridley and McCloskey demonstrate that trade is nothing new to humans, and the way that people associate consumerism entirely with modernism is misguided. Any discomfort that people feel about trade today must have been felt before throughout the ages. The authors also explain how the constant growth of trade is actually a great thing, and does not abandon the virtues we value. Yet people feel that the market does not instill these virtues. So what is the source of this discomfort?

3. THE IMPERSONAL NATURE OF TRADE

3.1 Evolution of Impersonality in Trade

Trade has changed dramatically over time. Centuries ago, two people would simply get together and trade spices for fabrics. As societies developed, people started using goods with inherent value (i.e. precious metals like gold) to trade with one another. Using money to purchase goods and services takes away the requirement of trading one final good or service for another. In this case, gold serves to extend the number of parties involved in and benefitted by the trade. It also allows two people to trade without directly swapping the goods they desire. The necessary downside of evolving to our system of modern money is that this trading process becomes ever more impersonal.

3.2 How has the Introduction of Modern Money Affected This Impersonality?

In “Money is Always Personal and Impersonal,” anthropologist Keith Hart explains how many feel that money, and consequently the trading that takes place with this money, “stands for alienation, detachment, impersonal society, the outside,” and that its “origins lie beyond our control.” It is important to note this can be true of any good that is used as a medium of exchange, whether it is gold or salt. Karl Marx popularized this sentiment through his ideas about the “cash nexus” and the dehumanization of money. Hart goes on to hypothesize that peoples’ desire to return to more personal methods of exchange evolve out of their inherent need to exercise more control over their own lives.

Hart concludes that money is both personal and impersonal. On the one hand, money can be viewed as very personal since it has a way of “connecting” two people or groups who would never have previously known one another. It decreases our self-reliance, which naturally makes us more communal. Additionally, money and other mediums of exchange allow us to disregard information about the previous behavior of the person(s) with whom we are trading. We do not have to know anything about who they are or where they come from; all we need to know is the price for the good or service in question.

In “The Coordination Value of Monetary Exchange,” Gabriele Camera and Marco Casari set forth a very different theory. They model impersonal exchange in a large-scale economy using only four players. All the players remain anonymous, and they only exchange information directly related to the trade they are trying to make. Two players are matched up and subjects can either give or receive a good (only one player in the set is given a good). Camera and Casari design the model so that the player without the good values the good more than the player with the good. Therefore, making a series of inter-temporal trades is the only way to maximize efficiency and utility for the community. Once a trade is made, each player is immediately re-matched with another player.

Camera and Casari conclude that even in a four-person economy with indefinite interaction, it is impossible to reach efficiency without allowing for relational contracts and direct reciprocity. This means people in the model do not end up at the optimal level of trading because they are not allowed to make

contracts based on trust (i.e. if you give me the good now, I will give up the good in my next trade), and they are not allowed to give explicit agreement to favor cooperation in all future trades (i.e. they were not allowed to confer to determine the 'optimal' level of cooperation). People are of course unlikely to give up the good they have to give to an anonymous player without having any sense that the player would ever return the favor. Once tickets (with no inherent value) are introduced into the system, players were more compelled to intertemporally give and receive goods. Essentially, the tickets allow for people to give out IOU's without their trading partner having to trust, in the most personal sense of the word, that they would pay them back. Instead of players A and B directly exchanging goods, player A could give player B an IOU in the form of a ticket, and player B could cash in his IOU by trading his ticket with player C. In this case, money clearly facilitates cooperation by allowing for contracts in which each player who agrees to cooperate and give up the good he or she owns is assured she could get the good back at a later trade if she chose to.

The model shows the relationship between money and impersonality in an entirely new way—money might not cause alienation and detachment, but rather it can facilitate cooperation in a society that is already large and impersonal. Modern money helps us to maximize utility in such a society. Additionally, the introduction of the tickets dramatically increased the probability that an exchange would occur. Since trust plays such an important role in making contracts, the players were inclined to support this system of tickets because it simulates the phenomenon of trust. They greatly lowered transaction costs and allowed the simulated society to reach its maximum level of utility. In this case, the tickets allowed the participants to feel an increased trust in their trading partner—people knew they would receive a ticket if they cooperated.

3.3 People Think of Modern-Day Trade as Impersonal. How Dramatically Do People Change Their Behavior to Avoid This Impersonality?

3.3.1 Buying Local

Buying locally produced goods can be viewed as a way for people to take trade to a more personal level. By examining how likely people are to prefer locally produced goods, and by noting the price increases they are willing to incur to buy local goods, we could shed light on how averse people are to buying goods from unknown origins. According to a March 2009 article from Adweek,

"Buying local" remains more a niche phenomenon than a mass movement, according to a Mintel report released this month, based on November polling. Just 17 percent of the respondents said they buy local products and services "as often as possible." Thirty percent are "aspirational locals"—people who say they'd like to buy local goods but don't know where to find them. Fruits and vegetables are the categories in which respondents make local purchases most often.

According to a 2006 article from the Journal of Food Distribution and Research, "concern about the cost of food significantly decreases the probability of buying local." Chowhound, a popular online food discussion board, shows that

non-locally produced blueberries cost an average of \$2.25 for a small container while a similarly sized package of blueberries from a local farm costs around \$3.50. Since locally grown food tends to cost more than food from distant lands, consumers tend to avoid these products.

Yet this movement has garnered a lot of support despite higher prices. In "Lowdown on Buying Local", Desmond O'Rourke cites a study done by Dawn Thilmany, a prominent agriculture and resource economist, on consumers' willingness to pay for locally grown foods. She found the average consumer was willing to pay a seemingly large 38.6% premium for a melon that was advertised as locally grown and produced.

The Long Island Farm Bureau states the "Safe & Abundant Food and Plant Supply" is the number one reason to buy local goods. They claim, "When you buy local, you know where your food comes from! You also know that strict regulations and policies are put into place to keep your food safe for you and your family." Based on the data, it seems that regardless of whether or not these claims about buying local are true or consistent, people do act on the impulse to buy local.

On the one hand, I could see how buying local is a rational behavior since people tend to trust and trade with people from their own communities more than outsiders. However, as we explored above, requiring too much trust could result in too few trades. The market has a way of simulating trust where it might not naturally exist. Supermarket rankings are readily available, and rating and reviews sections on supermarket websites are increasing in popularity.

3.3.2 Protectionism and Xenophobia

I would like to start this section on protectionism with a discussion about what it means to be a protectionist or a xenophobe. Since foreign workers would be prevented from working for United States employers, United States workers should then be prevented from working for foreign employers. Should foreign businesses be prevented from investing in and working with American businesses? In "More Sex is Safer Sex", Steven Landsburg tackles what for him is the morally compelling issue regarding protectionism—that protectionism is racism. He writes, "Politicians demanded tax incentives to reward firms for hiring whites instead of blacks. Those same politicians endorsed 'Right to Know' legislation, to alert consumers when products were produced by the 'wrong kind of workers.' They embraced slogans like 'Buy White.'" Typically the debate around protectionism has nothing to do with this moral issue, but rather with problems that people have with globalization and their perceptions about how foreigners affect the American economy.

Some people are averse to the impersonality that accompanies globalization. As regional economies started to get larger and more developed, and as technological growth started to boom, smaller economies began integrating and forming larger global economies. In "Globalization and Backlash: Polayni's Revenge," Brian Burgoon claims that "globalization might well spark demands for national autarky—not only economic protection, but also broader xenophobia and anti-democratic nationalist traditionalism." This is not a new phenomenon. Since globalization conjures up such negative feelings in some people, it is worth exploring some reasons why this might be the case.

One reason people might fear globalization is that they are worried foreign goods might not be as safe as goods produced in the United States. In "Total Recall on Chinese Imports: Pursuing an End to Unsafe Health and Safety Standards Through Article XX of GATT," Elvira Cortez calls attention to the imposition of all out bans on Chinese imports, particularly toys, after the recalls of 2007. Cortez mentions how after the recalls, people began to "raise questions as to the safety of all Chinese-made toys and stress the need for China to improve its health and safety standards so that it does not risk becoming subject to harsh counter measurements from the United States." While this might not look like an outright manifestation of xenophobia since it is a matter of simply buying safe goods regardless of origin, people tend to pay more attention to recalls of foreign goods than to recalls of U.S. produced goods. Looking briefly at the website for the US Consumer Product Safety Commission, there were over 45 recalls in March 2011 alone, yet the public is not alarmed by this. According to a poll conducted by The Gallup Organization, 94% of people polled said they would prefer to buy food grown in the United States than food grown in China, even if the U.S. grown food costs twice as much. Eighty-two percent of those polled had similar feelings about toys produced in the United States.

Some are uncomfortable buying goods from certain countries because they have negative perceptions of their government or people. We placed trade embargos on Cuba in the 1960s because many disagreed with their Communist government. Obtaining oil from the Middle East is an often-contested practice because of social and religious practices specific to those countries. Another often protested source of goods are countries like India, which are known to use child labor. When people do not know about the political and social climate that their goods were created in, they are often hesitant to readily buy these goods and openly support trade.

The main issue that most people have with foreign goods is that when they are produced out of this country, they are less able to exercise control over the methods of production. Many feel that goods produced in the United States are safer and produced more ethically than goods from other nations, so they have a preference for American goods. This may or may not be a correct assumption; regardless, people do not know much about the climate that American goods are created in so it is inconsistent to have a blind preference for American goods. Generally, people tend to overestimate how much we spend on foreign goods.

Many people fear the thought of goods produced in other countries, and they overestimate the extent to which we even import these goods, causing United States politicians to rally for a substantial amount of protectionist legislation. We have tariffs, import quotas, anti-dumping legislation, and subsidies directly given to American companies to help them compete with foreign businesses. All of this protectionist legislation is driven by the influence of American producers. When an American company feels threatened by a foreign company selling substitute goods, it is in their interest to use their votes and wallets as leverage against politicians. According to an article from the BBC, Michigan has given Ford millions of dollars in subsidies over the years. In 2007 alone, the state gave Ford over

\$300,000,000. National tariffs on foreign cars are around 2.5% and are hovering around 25% on pick-up trucks. When John Kerry ran for president in 2004, he was applauded for wanting to alter the tax code so that companies had less of an incentive to set up shop abroad. Our current administration is no stranger to protectionist policies. Just a couple of years ago, President Obama placed a 35% tariff on low cost tires from China. The effects of this tariff have been significant. Since the tariff made Chinese tires so expensive, American tire companies were able to increase the price of their own tires dramatically and still beat out their Chinese competitors. "Goodyear, for example, raised prices by 6 percent starting in December. The company said the price rise was to cover an increased cost of raw materials. Bridgestone Americas Tire Operations notified its dealers in October of a price increase of up to 15 percent on certain passenger and light truck tire patterns because of the tariff, according to a written statement provided by Don Darden, a Nashville-based spokesman for the tire manufacturer." The pervasiveness of all of these protectionist policies demonstrates how much support they receive from Americans.

While support for these protectionist policies could come from more than a fear of foreigners, xenophobia no doubt plays a role. We are one of the most diverse countries in the world, yet this "us" versus "them" mentality remains as an omnipresent force. The effect of American producers on facilitating this sentiment is clear; their attempts to influence the public to support protectionist legislation certainly serve to "fan the fear flames." We naturally fear what is different from us as well as what we do not understand; producers take advantage of and cater to this fear.

3.3.3 Preferences for Smaller Trading Circles

In "Personal Versus Impersonal Trade: The Size of Trading Groups and Contract Law," Robert Cooter and Janet Landa set forth a theory about the way the size of trading parties affects willingness to enter into contracts and the number of contracts that will result from various sized groups. As the size of the trading groups increases, so does the diversity of possible trades. People are more willing to enter into contracts if there are more options available. As the number of possible contracts increases, the probability that an "ideal" contract will arise also increases. Yet as the groups expand, personal ties between group members become more and more estranged. This compels people to make their contracts more formal, so their contracts are more likely to be enforced. Without trust, people would feel more pressured to make the stipulations of their contract more precise and to have the agreement about the trade written down officially. Formalizing contracts increases the price of making these contracts, so the number of contracts made would predictably decrease. There is a tradeoff between the increase in number of contracts from diversity and the decrease in number of contracts resulting from the increased cost to making more formal contracts.

We shall define group size as the number of members of a community that trade with one another. Cooter and Landa argue that when a representative individual makes a private profit-maximizing decision, he will choose a group size that is too small. His mistrust of other people and resulting increase in

price is too high from a societal standpoint. Additionally, people should not be given free entry into one's trading group since then, "new entrants treat the pool of trust as a free resource" and do not give enough value to trust in making contracts. This implies that there exists a price greater than zero for admission into a trading society that balances the cost of less trust and the benefit of diversity. This price can be thought of as the correct level of "credentials" necessary to be a worthy trading partner; this can range from having a personal relationship with the person you are trading with to having conclusive evidence that you will be able to hold up your end of the bargain.

So what does this mean? Perhaps people are too skeptical of the impersonal nature of trade. People tend to be too mistrustful of others to maintain an optimal level of trade. Conversely, people could just as easily overestimate the level of trustworthiness of people they know. These ideas that Cooter and Landa discuss in their paper could be extended to trade between various group sizes. Many might think that an individual trading with a large group, say a worker trying to formalize his working contract with his employers, should be mistrusting of the contract and worried of coercion. Assuming that the employers act in a generally trustworthy way, social utility might be higher if we learn to extend this trust when trust is due.

4. UNFAIR TRADE

The fair trade movement has grown dramatically in the past decade. In 1998, UK residents spent about 17m pounds on goods carrying the Fairtrade label; this number spiked to 712.6m pounds in 2008. The same article claims that "ethical consumption" is a growing market. It conjectures that the wealthier we become, the more we are able to care about the nature of our consumption and the more we can choose to consume more ethically. The author recognizes that the higher prices of these goods still have an effect on how prolifically they are bought, but he concludes that most consumers do have a commitment to "being good."

How did this desire to "be good" play out statistically? In "Do Ethical Consumers Care About Price? A Revealed Preference Analysis of Fair Trade Coffee Purchases," the authors rigorously explore how much "ethical consumers" respond to price by calculating their willingness to pay for goods labeled as fair trade, specifically for coffee. The authors set up an econometric model to determine how responsive consumers are to changes in the price of fair trade coffee. They use medium roast and dark coffee as controls. They found that the decision to buy fair trade coffee was not as price sensitive as the decision to buy either medium or dark roast coffees. While price and consumption of fair trade coffee were negatively correlated, they were not nearly as negatively correlated as the other varieties. These results were statistically significant. The price elasticity for the demand of fair trade coffee was -0.4217, which is classified as moderately inelastic. At -1.5582, the price elasticity for the demand for other varieties of Columbian coffee was much more elastic.

In "Knowledge Map of the Virtual Economy," Drs. Lehdonvirta and Ernkivist explain how out of \$70 million in gross revenues from coffee sales, only \$5.5 go to developing nations. These numbers demonstrate that the economic value

of coffee production is not in these developing nations, and distorting supply and demand to make it seem like that is the case is only more harmful in the long run.

Many are skeptical about engaging in trade that they think is generally unfair. Why should someone from Africa get paid 1 cent to do work that Americans are paid 10 dollars for? What about when one party seems to benefit much more from a trade than the other party does? Even if everyone is in agreement that both parties entered into the trade without being coerced, it still makes some people uncomfortable. This could be due to a misunderstanding about the nature of trade. Without understanding how trade works or how it benefits everyone involved, it is easy to think that certain parties are getting coerced, but people have to remember that trade is not a zero-sum game.

I think it is important to conclude this section with an economic analysis of fair trade. The idea behind the fair trade movement is that farmers would be guaranteed a higher price for coffee than they are currently getting. This would establish a price floor, which would cause supply to exceed demand. The farmers would naturally over produce, and middlemen would need to arise to siphon out the extra demand. At the same time, observable prices for fair trade coffee would increase, causing an even greater increase in supply. This would cause great distortion in the market, and the creation of 'deadweight loss' by inserting the middlemen. The problem with all of this is that a reason why people think coffee prices are too low is because there is so much excess supply, and a price floor makes this problem even worse.

5. FEW PRODUCE GOODS THEY ACTUALLY USE OR KNOW HOW TO MAKE ENTIRELY

"Here is an astounding fact: Neither the worker in the oil field nor the chemist nor the digger of graphite or clay nor any who mans or makes the ships or trains or trucks nor the one who runs the machine that does the knurling on my bit of metal nor the president of the company performs his singular task because he wants me [a pencil]. Each one wants me less, perhaps, than does a child in the first grade. Indeed, there are some among this vast multitude who never saw a pencil nor would they know how to use one. Their motivation is other than me. Perhaps it is something like this: Each of these millions sees that he can thus exchange his tiny know-how for the goods and services he needs or wants. I may or may not be among these items." – Leonard Read, "I, Pencil" ²⁸

Who knew the story of a simple pencil could shed so much light on the miraculous nature of trade? It is mind-boggling for people to think of the amount of work and specialization required to make even the most simple of objects. It seems that people think of motivation as too directly related to the cause and effect. If I put it in a certain amount of work in order to do something, it is because I want to reap some direct reward from that work. I am motivated to take out the garbage because I don't want to smell rot. Trade and specialization work in such a different way that it is hard to reconcile these distinct types of motivation. Motivation to work comes from the desire to use the rewards of your labor to purchase other goods and services that you desire. The haziness of this cause and effect relationship has

become ever more complicated by the introduction of money and increased specialization of our society; in order for people to fully understand where their ability to purchase a good at the supermarket came from, they would have to understand how their money came into their hands and all of the jobs of all of the different people that have contributed to the production of that good—and that’s just a start. Certainly no single mind could understand all of this, so it is a reasonable source of discomfort.

This sense of discomfort could relate to why people feel that fair trade coffee is more ethical—they do not understand why African farmers are paid 1 cent for the same work American farmers earn \$10 for. Wage is not a “choice;” it is a direct function of marginal product of labor.

6. TRADE MUST NEED A MASTER DESIGNER TO BE SO GREAT... RIGHT?

One of the main reasons people feel unsettled about trade is that they don’t understand how a system of trading could evolve. Without knowledge about how prices allocate goods, it is easy to understand where this confusion comes from. Frederick Hayek addresses this in “The Trend of Economic Thinking” stating, “we still refuse to recognize that the spontaneous interplay of the actions of individuals may produce something which is not the deliberate object of their actions but an organism in which every part performs a necessary function for the continuance of the whole.”²⁹ It is counterintuitive to think something so spontaneous could be better than anything the human mind could ever come up with.

While people tend to have too little trust in other individuals, they seem to place too much faith in the hands of designers. People think that if they cannot understand something, an expert would be more suited to understand and design it. This intuition is particularly untrue in regards to trade. Since all trading is contingent upon the preferences of both parties, no designer or expert could possibly attempt to understand, much less hypothesize, about the preferences of different parties.

7. WHAT IS TRADE?

One of the main issues with leading a discussion about trade is that trade means different things to so many people. What is often a limiting factor in a discussion about trade is that most people think of trade as the direct exchange of goods and services for money or other goods. This definition does not include nearly enough we can think of almost anything voluntary as trade. When I offer to take out the trash in my apartment it is because I assume that my roommates will take out the trash on another day, or just that the happiness they feel when I take out the garbage makes it all worth it for me. When people maintain this limited definition of trade, it often skews how they evaluate trade.

The reason why trade works is not intuitive. It is difficult to understand that if one country is the most efficient at producing every single possible good, it still makes sense to trade. It is not readily clear that trade is not a zero-sum game, but it really is possible for everyone to win. Leonard Read concludes “I, pencil” with some words of wisdom that could help quiet these discomforts that people have: “Have faith that free men and women will respond to the Invisible Hand. This faith will be

confirmed.”³⁰

8. CONCLUSION

There were a few recurrent psychological ideas that help explain why people are hesitant to accept free trade:

- People do not like to give up the sense of being self-sufficient
- Many do not accept social mechanisms that they don’t understand
- Most are too cautious about the size of the group that they trade with
- People are naturally xenophobic
- People like to feel like they are acting in an ethical way
- Many are concerned about knowing the origins of their goods
- People are skeptical that trade could sustain itself without intervention
- Some details about how trade works are not intuitive

Underlying all of these issues is a concept that Friedrich Hayek focuses on in “The Trend of Economic Thinking”: people are generally hesitant to accept economic ideas. Hayek argues that people think that since economics is a social science, the results should be intuitive and easily understood. Many do not realize that the scientific method could be applied to social problems. The reason why I started this essay with such basic examples about trade, in which the mutually beneficial nature is readily apparent, is that most would agree that individual and private trade is beneficial. Yet for the reasons listed above, people do not extend these ideas to trade in the larger sense. Hayek comments, “the task of the theoretical economist... consists essentially in the demonstration of the inconsistencies in a kind of ordinary reasoning which everybody employs and the validity of which no one could ever doubt were it applied to simple cases where it could easily be understood.”³¹

Throughout the process of doing research for this paper, I have realized that there is an economic tool that other people are hesitant to understand and evaluate—looking at large scale issues in a simplified way with some assumptions about the nature of the problem. *Ceteris paribus*, in other words. People seem to be very resistant to apply this tool to try to understand economic ideas. As Adam Smith once said: “The propensity to truck, barter and exchange one thing for another is common to all men, and to be found in no other race of animals.”³² And that is a valuable thing.

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