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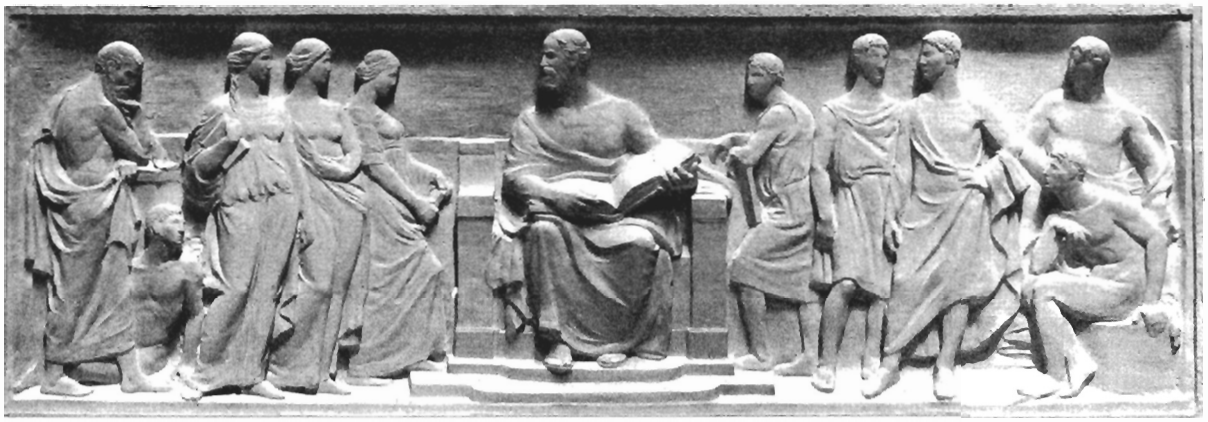

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Preface

To paraphrase Robert Fulghum, *All I really need to know about how to live and what to do and how to be I learned in…* undergraduate research. One of my most personally and professionally inspiring learning experiences was working as an undergraduate student side-by-side with a teacher-scholar in the pursuit of knowledge.

I learned about the thrill of inquiry and discovery, the importance of careful and critical thought, and the joys of collaboration. I learned that the magic is not just in finding an answer but more so in discovering new questions. I learned to appreciate that *variance* is at the heart of scientific inquiry—and humanity; phenomena are of interest because of variability and difference. I gained appreciation for collaborative critical thought; viewing phenomena from different perspectives enriches understanding and advances knowledge. The inevitability of trial and error reminded me of the unexpected challenges in life and the lessons they often contain.

I celebrate the transformative learning experiences represented in this volume. To my teacher-scholar colleagues, I share my deep respect for your generosity in these powerful learning partnerships.

To the student authors, I salute the courage with which you opened yourselves to these challenging learning experiences. Relish the experience and carry forward the power, passion, and potential of scholarly inquiry.

Beth Paul
Professor of Psychology

A Message from the Editor

The 2004–2005 academic year marks two major milestones for The College of New Jersey. First, the College celebrates the sesquicentennial of its founding in 1855. Established as a normal school, TCNJ has evolved into a comprehensive institution with an impressive liberal arts and sciences foundation. Second, coincident with this celebration, TCNJ is inaugurating its transformed curriculum in 2004–2005, which is designed to provide our students with the most rigorous, intensive, and up-to-date learning experiences. Since its founding in 1998, *TCNJ Journal of Student Scholarship* has grown with the College. The fruit of this year's submission process is now in your hands. The quality of the wide range of essays published in this volume reflects the firm commitment of students, faculty, and administration to premiership among the nation's undergraduate colleges.

I wish to thank the many people who have contributed to Volume VII of *TCNJ Journal of Student Scholarship* beginning with the students and the professors who encouraged them. I would also like to extend my gratitude to those faculty members who generously served as advisers and sponsors for each paper submitted. The administration of President R. Barbara Gitenstein and Provost Stephen R. Briggs graciously provided moral and financial support and release time, without which this volume would not have been possible. In addition, Vice Provost Suzanne Pasch has staunchly supported the *Journal* since its inception. The staff of the Office of Academic Affairs, including especially Nancy Freudenthal and Ellie Fogarty, has been kind, patient, and helpful with a variety of concerns and inquiries. I also extend thanks to Anthony Marchetti and Cindy Friedman of the Office of College and Community Relations. For consultation on production matters, I thank Lisa Angeloni, director of admissions. I offer special thanks to the members of the editorial board of the *Journal* for lending their time and expertise to the reviewing of papers in the midst of many other responsibilities. Paulette LaBar of the Department of English kindly and expertly assisted in the editing of the essays printed in this volume and periodically updated the Web site of the *Journal*. I would also like to thank my wife, Jeanne Conerly, and our daughter, Katherine, for their support and understanding during an extraordinarily busy year. To Professor Beth Paul, whose many responsibilities include chairing the Department of Psychology, I owe thanks for her contributing the preface to Volume VII. Finally, I would like to thank Associate Editor Romulo Ochoa for his wise advice and careful editing of the science essays. As these acknowledgements indicate, this volume is the product of a community-wide effort.

For information about the *Journal*, including submission procedures, format requirements, and application forms, please telephone the editor at 609.771.2155 or contact him by e-mail at dventuro@tcnj.edu; or, visit the *Journal* Web site at http://sjournal.intrasun.tcnj.edu.

Now, I invite you to turn to the essays published in this volume, and to read and enjoy them.

David Venturo
Editor
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Contents

VOLUME VII

Political Translation: The Case of John Dryden and Juvenal

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Abstract

In the 1690s, John Dryden, at odds with the English civil and ecclesiastical authorities, used his translations of classical poets such as Juvenal as a vehicle for commenting indirectly on the affairs of his own times. By speaking ventriloquially through Juvenal, Dryden was able to satirize his own society, but in such a way as to avoid punishment or censorship by the authorities by insisting that he was merely translating the words of a classical predecessor, and not making any personal claims himself.

Introduction

John Dryden's translations of Juvenal's satires appeared in late 1692, four years after the Glorious Revolution in which William of Orange (later, William III) supplanted James II from the English throne. Dryden, refusing to reject his king or his Roman Catholicism, became an outcast in William's Protestant England and was quickly dismissed from his government positions of Poet Laureate and Historiographer Royal.[1] Suddenly, Dryden found himself in the precarious position of being a politically minded poet under an inhospitable rule. In *Persecution and the Art of Writing,* Leo Strauss discusses the tendencies of writers in dangerous environments to express their message between the lines:

> Persecution, then, gives rise to a peculiar technique of writing, and therewith to a peculiar type of literature, in which the truth about all crucial things is presented exclusively between the lines. That literature is addressed, not to all readers, but to trustworthy and intelligent readers only.[2]

Strauss's principle rings very true for Dryden's post-Glorious Revolution writings—specifically, his *Satires of Juvenal.* Dryden, moving to translation after an unsuccessful return to playwriting, had no regular salary and certainly needed the financial support that translation would provide. He was, nonetheless, bitter at the social and political climate that robbed him of his financial security, and he regarded translation as a vehicle through which he could covertly disseminate his social and political criticisms. The useful function of translation, and certainly the main reason why Dryden turned to it after the Glorious Revolution, is the plausible deniability that it affords. Under the rule of William III, Dryden did not have the freedom to comment openly on society as he had under Charles II and James II; any overt criticisms of society might have led to harsh persecution. Translation, then, offered Dryden an effective way to remove his person from his poems—he could always claim that the social and political criticisms found in the translations were Juvenal's, rather than his own.

The Third Satire of Juvenal is a harsh indictment of the vices of Roman society, spoken through the voice of the character, Umbricius. Dryden's translation of this indictment begins:

> Thus then Umbricius (with an angry frown,
> And looking back on this degen'rate town):
> 'Since noble arts in Rome have no support,
> And ragged virtue not a friend at court,
> No profit rises from th' ungrateful stage;

My poverty increasing with my age,
'Tis time to give my just disdain a vent
And, cursing, leave so base a government[3]
(37-44).

Through the persona of Umbricius, Dryden is chastising London for its lack of support of the arts, and, consequently, for leaving him a poor and weary old man. Dryden would have us believe that this is a mere translation of Juvenal's words when, in reality, his own message is—here and throughout the satire—interwoven with Juvenal's words. Through broad translations of Juvenal's words and striking interpolations of his own sentiments, Dryden is able to embed his own criticisms, while taking responsibility only for the poetic style.

David Bywaters argues that, "Dryden [...] is attracted to translation because it allows him the rhetorical advantage of appearing before his public as a poet and only a poet." "As a poet" is exactly how Dryden hoped to be seen by the majority of his readers—particularly the authorities whom he was criticizing. "Dryden, then," Bywaters continues, "claims responsibility in his translations only for poetic style; social and political criticism is always the work of his originals."[4] This is the plausible deniability that translation affords. Dryden could always claim that the social criticisms were the work of his original author—especially when translating a text as laden with social criticism as *The Satires of Juvenal*. It would be extremely difficult for anybody not familiar with Juvenal's text to find Dryden's interpolations—a fact Dryden relied on for his safety.

Before 1688, however, Dryden's safety was much less of an issue. Under Charles II and James II, Dryden enjoyed a relationship which the Romans would characterize as *amicitia*.[5] *Amicitia* (etymologically based in the Latin *amicus* and Greek φιλία—signifying an emphasis on friendship and affection) was a social system linking a Roman politician with a vast network of personal relations for the purpose of advancing the politician's career. The relationship was characterized by a give and take by all of those in the web: the politician provided protection and certain freedoms to his supporters who, in turn, would provide political backing. Those linked to the politician were often family, close friends, political allies, as well as poets.[6] Dryden's function in the courts of Charles II and James II would have typified *amicitia*. As Poet Laureate and Historiographer Royal, Dryden was, of course, expected to promote, if not defend, the policies of his king through supportive and often propagandist poems. Dryden did, however, enjoy certain freedoms through his political associations. He had a guaranteed salary (though it was often in arrears) and could count on consistent patronage and, accordingly, had plenty of leisure to write what he pleased.

Thus, when Dryden's desire took him to translation, he had no need to deny the liberal translation methods which he used. In the preface to his 1680 publication of *Ovid's Epistles, Translated by Several Hands* he spells out very clearly the options available to a translator:

> All Translation I suppose may be reduced to these three heads. First, that of the Metaphrase, or turning an Authour word by word, and Line by Line, from one Language into another [...]. The second way is that of Paraphrase, or Translation with Latitude, where the Authour is kept in view by the Translator, so as never to be lost, but his words are not so strictly follow'd as his sense, and that too is admitted to be amplified, but not alter'd [...]. The Third way is that of Imitation, where the Translator (if now he has not lost that Name) assumes the liberty not only to vary from the words and sense, but to forsake them both as he sees occasion: and taking only some general hints from the Original, to run division on the ground-work, as he pleases.[7]

He goes on to discuss his preference for the "Paraphrase," or middle ground. As a paraphrastic translator, Dryden would have no apprehensions about interjecting certain interpolations into his translation that are not found in the original. In fact, at the close of this essay he boldly claims that he has gone even further than a paraphrastic translation: "I have transgress'd the Rules which I have given; and taken more liberty than a just Translation will allow."[8]

In 1685, five years after the publication of the preface to the Ovid translations—and three years prior to the Glorious Revolution—Dryden published *Poems from Sylvae* with a preface in which he again discusses the nature of translation. Dryden remarks, "It was my Lord Roscommon's 'Essay on Translated Verse', which made me uneasie till I try'd whether or no I was capable of following his Rules."[9] The allusion to Roscommon refers to the poem, "An Essay on Translated Verse," to which Dryden attached a laudatory poem for its 1684 publication. Roscommon, on the question of how much of a translator's own voice should be found in a work, says, "He only proves he understands a text,/ Whose exposition leaves it unperplex'd" and, "Excursions are inexpiably bad;/ And 'tis much safer to leave out than add" (200-201, 216-217).[10] Clearly, when Dryden mentions the 'Rules' of Roscommon, he means the principle of a translator following the original author very closely. Thus, when he writes later, "I must acknowledge, that I have many times exceeded my Commission; for I have both added and omitted, and even sometimes very boldly made such expositions of my Authors as no Dutch Commentator will forgive me," he is placing himself firmly in the paraphrastic school of translation; perhaps even leaning towards Imitation.[11]

After the Glorious Revolution of 1688, Dryden did not have the freedoms which he enjoyed in the courts of Charles and James. No longer was Dryden involved in a system of *amicitia* but now, rather, *clientela*. *Clientela* was a system of dependency, a system linking the inferior class to the upper. There was nothing of the give and take present in *amicitia*. Freed slaves, for instance, became *clientes* to their former masters; common citizens in towns would be *clientes* to a wealthy leader.[12] Though *amicitia* was not a direct counterpart to Restoration patronage, Dryden translated *amicitia* as 'patronage' and believed them to be corresponding practices. In 1697, Dryden wrote *The Dedication of the Pastorals* to Hugh Lord Clifford, the son of one of Dryden's former patrons, telling Clifford:

> You are acquainted with the Roman History, and know without my information that Patronage and Clientship always descended from the Fathers to the Sons; and that the same Plebeian Houses, had recourse to the same Patrician Line, which had formerly protected them: and follow'd their Principles and Fortunes to the last.[13]

Clifford was one of the many prominent figures who purchased a five-guinea subscription which funded Dryden's publication of *The Works of Virgil*. It is clear that Dryden believed himself to have passed from *amicitia* with Clifford's father as a patron into *clientela* with Clifford himself as a subscriber. Regretfully, Dryden understood that, ever since the Glorious Revolution, he was a writer-for-profit and a writer who was no longer under the protection of the court.

The lack of political protection, however, did not discourage Dryden from expressing his views through poetry. He wrote with the belief that a poet served a vital function in society. Poetry, for Dryden, was meant to comment on society, to raise the consciousness of its readers, and to preserve an era for future readers. This mindset would not allow him to translate Juvenal's satires only poetically and neutrally; rather, it required a commentary on society. This commentary on social and political ills, however, could not be made openly. Accordingly, in the essay which served as a preface to the translations of Juvenal and Persius, *A Discourse Concerning the Original and Progress of Satire,* we find a much different rhetoric from Dryden concerning the nature of translation:

> We [...] have endeavour'd to make him speak that kind of English, which he wou'd have spoken had he liv'd in England, and had Written to this Age. If sometimes any of us (and 'tis but seldome) make him express the Customs and Manners of our Native Country, rather than of Rome; 'tis either when there was some kind of Analogy, betwixt their Customes and ours; or when, to make him more easy to Vulgar Understandings, we gave him those Manners which are familiar to us. But I defend not this Innovation, 'tis enough I can

> excuse it [...]. We shou'd either make them English, or leave them Roman." [14]

Clearly this stands quite drastically opposed to Dryden's 1685 assertion in *Sylvae* that, "if he were living, and an Englishman, [my interpolations] are such, as he wou'd probably have written." [15]

A Discourse is not a standard introductory essay but, rather, an elaborate example of Strauss's principle of writing between the lines. *A Discourse* is written to the Earl of Dorset, Dryden's old friend and patron, who served as Lord Chamberlain under William III. It was Dorset who, acting in an official capacity rather than in friendship, dismissed Dryden from his public offices and installed MacFlecknoe himself, Thomas Shadwell, as Poet Laureate. Dorset did, however—acting in friendship rather than duty—continue to support Dryden, as the former Poet Laureate gratefully notes: "your Lordship was pleas'd, out of no other Motive, but your own Nobleness [...] to make me a most bountiful Present, which at that time, when I was most in want of it, came most seasonably and unexpectedly to my Relief." [16] Throughout *A Discourse,* Dryden praises Dorset extravagantly, comparing him to nothing less than the sun and God. This is a demonstration of the power of poetry—Dryden is showing that writers have the power to immortalize, and that William III is a fool for not supporting him.

William, of course, is never named directly. To find William, we must turn to Dryden's *Argument of the First Satyr,* where Dryden writes:

> But our Poet being desirous to reform his own Age, and not daring to attempt it by any Overt act of naming living Persons, inveighs onely against those who were infamous in the times immediately preceding his, whereby he not only gives a fair warning to Great Men, that their Memory lies at the mercy of future Poets and Historians, but also with a finer stroke of his Pen, brands ev'n the living, and personates them under dead mens Names.[17]

Though Juvenal probably wrote during the reign of the Hadrian, Dryden erroneously thought him to be a subject of Domitian and in *A Discourse* writes, "wheresoever Juvenal mentions Nero, he means Domitian, whom he dares not attack in his own Person, but Scourges him by Proxy."[18] Though modern historians doubt whether Domitian's reign was as full of oppressive terror as is rumored, ancient writers (whom Dryden would have read) certainly characterize it as such.[19] Though never saying so directly, Dryden most certainly invites, if not encourages, his readers to find allusions to William throughout his translation.

Paul Hammond, in an argument similar to Strauss's, writes that Dryden's prefaces are "a lesson in how to read. In dangerous times, writers generalize their case and avoid particulars; they use names from the past as indirect allusions to contemporary figures; they describe one vice as a metaphor for another." [20] The lesson which Hammond is discussing is found in the subtext which Strauss argues arises from persecution. Strauss insists, "thoughtless men are careless readers, and only thoughtful men are careful readers."[21] Certainly, Dryden's covert criticisms of London society are meant for thoughtful, trustworthy, and intelligent readers. These same intelligent readers can be relied upon to find the message ingrained in *A Discourse* and not to be fooled by Dryden's claim that his translations are merely poetic endeavors. Juvenal satirizes the vices of Rome in such a way as to allow Dryden to embed his own social criticisms almost seamlessly. A close examination of Juvenal's original shows that Hammond is quite right in noting, "in some places the Latin is a pre-text, in others only a pretext."[22]

Juvenal's third satire presents the story of Umbricius as he is packing up and abandoning Rome. Frustrated with the political, social, and cultural environment of Rome, Umbricius decides to abandon his home in favor of the country town, Cumae. As he is leaving, Umbricius harshly indicts Rome in a long speech which comprises most of the poem. Dryden, intending this speech to be read in regards to London, coyly gives an extra edge

to Umbricius' words. Umbricius' speech affords far too many opportunities (which are readily capitalized upon) for Dryden's interpolations in his translation to be driven merely by poetics. The opening of the speech reads, "Hic tunc Umbricius [...] inquit," (21) ('Here, then, Umbricius says') which Dryden translates as, "Then thus Umbricius (with an angry frown,/And looking back on this degen'rate town)."[23] This added description of Umbricius and the city (ostensibly Rome, but in fact London) has no basis in the Latin—it is complete interpolation.

Later, when Umbricius vents his frustration concerning the influx of Greeks into Rome, Dryden translates, "Non possum ferre [...] Graecam urbem" (60-61) ('I cannot bear a Greek town') rather broadly as, "I hate, in Rome, a Grecian town to find" (106). 'Hate' certainly is a stronger verb than 'cannot bear.' Although they may be similar ideas in English, Latin distinctly used *odi* to express hatred.[24] Juvenal himself uses *odi* in his sixth satire—clearly, if he had meant to express hatred he would not have written *non possum ferre*. In the following lines, working very loosely off, "quamvis quota portio faecis Achaei?" (61) ('and yet, what portion of the dregs is from Greece?'), Dryden adds on his own, "to see the scum of Greece transplanted here,/ Received like gods, is what I cannot bear" (107-108). The term *faex* (*faecis* in the genitive) can be broadly translated as 'scum' and that is undoubtedly the word from which Dryden takes his cue, but he is clearly skewing Juvenal's meaning to his personal feelings.[25] Surely such a harsh interpolation was incited by Dryden's disdain for the Dutch that populated London after the ascension of William III.

Early in Dryden's translation of Juvenal's first satire, we see him translate, "tam patiens urbis" (31) ('so forbearing a town') as, "so lewd a town" (44). Clearly this is yet another case in which Dryden has changed the sense of Juvenal's original for personal—not poetic—reasons. It would be very difficult for any reader unfamiliar with Juvenal's original to detect this added spite for London. The same reader would most likely take lines 215-216 of the third satire, "At Rome (nor think me partial to the poor)/All offices of ours are out of door," to be Juvenal's words. Juvenal does mention the dire situation of the poor, "aut quod/ pauperis hic" (126-127) ('what sort of place is this for poor men?'), but Dryden's clear reference to the loss of his government positions (which, through Umbricius, gets blamed on society) is a very broad translation of the Latin.

Lines 43-44 of Dryden's translation read, "'Tis time to give my just disdain a vent/ And, cursing, leave so base a government." Yet again, there is simply no Latin counterpart for these lines—Dryden has inserted them on his own. Perhaps the most interesting element in this passage is Dryden's use of the word 'government.' Clearly, with the harsh rule of William III, the loss of both of his public offices, and the influx of Dutch immigrants who followed their king, Dryden's displeasure with English society focuses squarely on the government. Juvenal's third satire, however, makes virtually no mention of governmental issues, never discussing either the senate or the emperor. Line 47 of Juvenal's original uses the word 'comes' (which Dryden spins into the very liberal translation, "Like a dead member from the body rent,/Maimed and unuseful to the government" (87-77)) and the word 'praetor' (which Dryden transliterates) is found in line 128. Both of these are Latin terms for government officials, but there is never any direct mention of the Roman government.

Dryden's Umbricius, in line 50, insists, "Now, now, 'tis time to quit this cursed place/ And hide from villains my too honest face," which Juvenal's Umbricius never utters. We have now seen the phrases, 'degen'rate town,' 'base government,' and 'cursed place' all used by Dryden (and not by Juvenal) to describe Umbricius' soon-to-be former city. That city was Rome, but Dryden, in taking the first seven lines of Juvenal's account of Umbricius and more than doubling them into 15 lines, has made it London.

Through translation, Dryden found a way to separate himself quite brilliantly from any association with his message while still boldly satirizing his society. Dryden regarded Juvenal's work as a vehicle through which he could safely make his political argument. Michael Wilding, in addressing the true nature of these translations writes, "Dryden has found in Juvenal a voice that readily becomes his own."[26] What Wilding recognizes is the very aspect that Dryden hoped the authorities would neglect—the parallel between Juvenal's Rome and Dryden's London is, much more than the poetry, what begot these translations. In 1692, Dryden was the same paraphrastic translator as he was in 1680, reserving the same freedom to amplify the original sense of an author, but his later interpolations are much more incendiary. The late 17th century was a dangerous time for John Dryden and certain precautions were a necessity for him; one of which was not being as bold as he had been in the past in publicly discussing his methods of translation. In what can perhaps be considered the swansong to his career, Dryden published a translation of Virgil's *Aeneid* in 1697, to which he attached a postscript addressing his talent for satire. Describing himself as being, "in my Declining Years" Dryden writes:

> Here is a Field of Satire open'd to me: But since the Revolution, I have wholly renounc'd that Talent. For who wou'd give Physick to the Great when he is uncall'd? [...] 'Tis enough for me, if the Government will let me pass unquestion'd.[27]

Dryden made full use of his plausible deniability to the end. It is clear that Dryden never abandoned his talent for satire, nor did he ever change his methods of translation. He did, however, very skillfully adapt to his times. The final decade of the 17th century was not a safe time for John Dryden; but rather than remaining silent he chose only to appear silent and express his message only to those who could read closely enough to understand it.

NOTES

1 James Anderson Winn, *John Dryden and His World* (New Haven: Yale UP, 1987). This and all other biographical information is taken from Winn.
2 Leo Strauss, *Persecution and the Art of Writing* (Glencoe: The Free Press Publishers, 1952) 25.
3 James Kinsley, *The Poems of John Dryden,* 4 vols. (London: Oxford UP: 1958). All quotations from Dryden's translations of Juvenal come from Kinsley, pp. 670-740. Line numbers are noted in the text.
4 David Bywaters, *Dryden in Revolutionary England* (Berkeley: U of California P, 1991) 124-25.
5 For further discussion on the nature of *amicitia* in Roman society see R. P. Saller, *Personal Patronage Under the Early Empire* (Cambridge: Cambridge UP, 1982); Peter White, *Promised Verse* (Cambridge: Harvard UP, 1993); David Konstan, *Friendship in the Classical World* (Cambridge: Cambridge UP, 1997).
6 Gian Biagio Conte, *Latin Literature: A History* (Baltimore: Johns Hopkins UP, 1994) 794.
7 Kinsley 182.
8 Kinsley 186.
9 Kinsley 390.
10 Taken from John Mathews Manly, ed. *English Poetry 1170-1892* (Boston: Ginn and Company, 1907).
11 Kinsley 390.
12 Conte 802.
13 Kinsley 872.
14 Kinsley 669-70.
15 Kinsley 391.
16 Kinsley 617.
17 Kinsley 671.
18 Kinsley 654.
19 Edward Togo Salmon, *A History of the Roman World from 30 B.C. to A.D. 138* (London: Methuen, 1957) 226.
20 Paul Hammond, *Dryden and the Traces of Classical Rome* (London: Oxford UP, 1999) 185.
21 Strauss 25.
22 Hammond 186.
23 Niall Rudd and Edward Courtney, eds., *Juvenal Satires I, III, X* (Wauconda: Bristol Classical Press, 1977). All Latin quotations are taken from Rudd. Line numbers are noted in the text.
24 "odi," def. 1 *Oxford Latin Dictionary,* 1982 ed.
25 "faex," def. 4 *OLD.*
26 Michael Wilding, "Dryden and Satire: 'Mac Flecknoe', 'Absalom and Achitophel', the 'Medall', and Juvenal," *Writers and Their Background: John Dryden,* ed. Earl Miner (London: Oxford UP, 1972) 224.
27 Kinsley 1424-25.

Natural and Unnatural Motion in the Poetry of William Wordsworth

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Abstract

Images of motion are central to much of William Wordsworth's poetry, especially the two-part *Prelude* (1799) and the "Ode: Intimations of Immortality" (1807). Major differences in the representations of movement and motion in these two poems reflect important ideological and spiritual shifts in Wordsworth's thinking between 1798 and 1807 about nature and the self. This essay explores the significance of those changes.

Introduction

In much of William Wordsworth's best known poetry, particularly in the two-part 1799 *Prelude* and the "Ode: Intimations of Immortality," images of motion are central. In each poem, several types of motion have thematic significance, including Wordsworth's physical motion, his metaphorical movement toward maturity, contentment, and poetic power, 'natural motion' or movement in his surroundings (of wind, water, animals, etc.), and the motion of the poems themselves toward a resolution. These images reflect the nature of Wordsworth's relationship with the natural world and his confidence in his poetic imagination. In fact, a major difference between representations of movement in the 1799 *Prelude* and those in the Intimations Ode, written several years later, corresponds to a significant ideological and spiritual shift in Wordsworth's thinking about nature and the self.

Before beginning a discussion of Wordsworth's relationship with 'nature,' however, it will be helpful to explain what he means by that term in the poems I will be addressing. In the two-part 1799 *Prelude*, Wordsworth typically uses 'nature' to mean the outdoors—"the common range of visible things." In the "Ode: Intimations of Immortality," the meaning of the word is widened: nature comes to signify everything on earth, or the earth itself, especially in opposition to the immortal, or non-earthly realm. Nature is, however, a sort of sentient being (or beings) for Wordsworth in both poems, a presence that is alternately joyful, solemn, helpful, or threatening, but always deeply concerned with *him*, always singling him out as a "favored being" and focusing "quiet powers...and.../severer interventions" on him, whether he wants them or not.[1]

In the several years between the completion of the two-part 1799 *Prelude* and the "Ode: Intimations of Immortality," Wordsworth seems to have become dissatisfied with nature. As a nurturer, an educator, as a means of fulfillment, and as a source of unalloyed joy, nature no longer contented him. In the Intimations Ode, the poet claims that nature—beautiful landscapes and the natural process of growing up—compels humans to forget their origins in the immortal world. Nature, in the Intimations Ode, is an overprotective mother, an object of restrained dislike and exasperated pity. The earth, a "homely nurse...even with something of a mother's mind...doth all she can/To make...her Inmate Man,/Forget the glories he hath known."[2] Wordsworth's addresses to nature

in the 1799 *Prelude* are significantly different. As Stephen Gill writes, in the early Prelude nature is a "generous, providential power" that is not a vehicle of forgetfulness but quite the opposite: nature, in providing the "pleasures and pleasing terrors of childhood," stimulates "memory's power both to retain an image of the self as one evolving whole and to draw nourishment from the past for the sustenance of the present and the future."[3] It is important to note, however, as Jonathan Wordsworth does, that in the 1799 *Prelude* Wordsworth is able to have an effect on nature equal to, or greater than, nature's effect on him.[4] Nature's "quiet powers" and "severer interventions" are, at times, less powerful than Wordsworth's own imagination:

> An auxiliar light
> Came from my mind, which on the setting sun
> Bestowed new splendour; the melodious birds,
> The gentle breezes, fountains that ran on
> Murmuring so sweetly in themselves, obeyed
> A like dominion, and the midnight storm
> Grew darker in the presence of my eye.
> Hence my obeisance, my devotion hence,
> And hence my transport.

Here, Wordsworth is celebrating his ability to give natural, commonplace objects and incidents the "certain colouring of imagination" that he mentions in the preface to *Lyrical Ballads*.[5] He has reverence for nature as an artist has reverence for his medium. He is devoted to nature because of his power to see it in many different ways, to enhance its beauty and ensure its place in memory. Wordsworth is confident, in the 1799 *Prelude,* in the ability of the human imagination to maintain a deep intimacy with nature—to receive nature's alternately gentle and terrifying "education," and to improve upon nature and invest it with human feeling. In the 1799 *Prelude*, nature and the poet are in harmony; the landscape of his imagination and the natural landscape are inseparable and complementary.

In the Intimations Ode, the poet recognizes another landscape, another mode of existence—immortality, which replaces earth and nature as the realm with which the poet most desires to merge. This is the major change: from the poet's harmonious coexistence with nature and satisfied preoccupation with his own mind in the 1799 *Prelude,* to his ambivalence toward nature and his need to be assured of something beyond the human mind in the Ode. In the 1799 *Prelude,* Wordsworth is not worried about losing his poetic vision as he grows older, which is the concern that torments him in the Ode. Rather, in the 1799 *Prelude,* the beauty of nature, and nature's responsiveness to the poet's emotions, are enough to fulfill him. This is a simple, even a childish fulfillment: the 1799 *Prelude,* in which Wordsworth first addresses the question of how the mind of a "favoured being" is "fashioned and built up," chiefly recounts incidents from childhood in which his imaginative power has been inspired or exerted. The adult Wordsworth's feeling that he has retained, as a "favored being," and through his vivid memories, this power to reshape the world, produces the happiness and confidence with which the 1799 *Prelude* is brimming. Images of motion in the 1799 *Prelude* corroborate this idea: movement in the poem—both the poet's movement and that of the world around him—is toward happiness, enlightenment, and the strengthening of imaginative power.

Images of motion in the 1799 *Prelude*, including the ways in which nature is described as moving and the poet's own movement, can be divided into two types. Motion that is slow, steady, and purposeful suggests Wordsworth, with nature's assistance, moving toward a fuller understanding of his own imaginative capabilities. Erratic motion in the poem tends to coincide with the moments of extreme joy or terror in which Wordsworth's imagination and the natural world merge most completely, when the poet is most able to project his feelings onto nature. The important generalizations to make about images of motion in the 1799 *Prelude* are that they are healthy and beneficial, that they are exhilarating and purposeful, and that the poet is

always journeying, hand-in-hand with nature, toward self-actualization. Sometimes he takes the lead, sometimes nature seems to 'push' him—but he is always moving in harmony with nature, and always in the right direction, towards pleasure, self-confidence, and maturity.

In the first lines of the 1799 *Prelude* Wordsworth asks the question that occupies him for the rest of the poem: "Was it for this?" Was it to ensure the success of my poetry, he wonders, that nature has employed the ministries of fear and love? Gill observes, "the antecedent of 'this' is implied in the very act of writing the poem and the answer is a jubilant yes."[6] Images of motion lend credence to the idea that nature has aided—and continues to aid—Wordsworth in his poetic attempts. The Derwent river makes "ceaseless music through the night and day,/Which with its steady cadence tempering/Our human waywardness, composed my thoughts/To more than infant softness." The steady, constant motion of the river acts on the child's thoughts, giving him direction, a capacity for introspection, even "a knowledge...of the calm/Which Nature breathes among the fields and groves." It is imperative that the child be exposed to the river's steady motion toward enlightenment and wisdom, for human institutions, the "dwellings of mankind," are "fretful" by comparison. Humans cannot be calm, constant, and steady; they move from place to place, agitatedly and without thought. Humans are "wayward"—their motion is in need of direction—and nature provides this direction. This distinction between the steadiness of nature and the waywardness of man, and the importance it places on immersing oneself in nature to improve one's capacity for thought, justify the poet's spending the rest of the poem recounting his own immersion in nature and its effect on his thought. The first images of motion in the 1799 *Prelude,* as I have shown, make the nature/man, steady/unsteady distinction clear; in the "spots of time" that follow, these images celebrate the success of the poet's merging with nature and overcoming his human waywardness.

The first childhood incident, or "spot of time," in the 1799 *Prelude* contains images of motion that suggest the strong, sometimes frightening purposefulness with which nature administers the child Wordsworth's education. In the Egg-Stealing episode, Wordsworth hangs over the edge of a cliff, suspended, it seems, solely by the "loud dry wind," the "blast which blew amain." To his bewildered eyes, the "sky seemed not a sky/Of earth, and with what motion moved the clouds!" It is this strange, beautiful motion of wind and clouds that ensures the "not ignoble...end" of Wordsworth's "inglorious" egg-stealing mission. The motion of the wind seems to hold the child aloft, both physically and spiritually, allowing him to see the unearthly sky and clouds, and to commune with the spirit of nature. He feels the wind blowing "through [his] ears," physically, intimately acting on his mind, blending with his thoughts, and making him aware of the power of the natural world. Motion is largely responsible for the formative effect of this episode on the child.

In the Boat-Stealing episode that follows, images of motion predominate as well, propelling the poet toward recognition of his own imaginative power. Here, Wordsworth's motion plays a more active role in the educative experience. As the child rows out onto the lake, he is vividly aware of the motion of the water as his boat moves through it. The wake or "small circles" his boat makes in the water melt together and form a "track/Of sparkling light" that follows him as he rows. These images indicate that he is moving in harmony with nature; his rowing causes the water to move, which creates the beautiful, ethereal track of sparkling light. Nature has embraced the young Wordsworth and is moving with him, even compelling him to move. He is being "guided," as he says, by the "Severer interventions" of natural "spirits," toward an experience that will fructify his poetic imagination.

The motion of the child's rowing reflects his guilt for stealing the boat; he rows "like a man who walks with steady step/Though bent on speed," as if walking away from the scene of a crime. Suddenly, he is startled by another, this time illusory, motion—the "huge cliff" rising suddenly "between [him] and the stars" and, horribly, "with measured motion, like a living thing" coming toward him. Badly frightened, the boy begins to row more forcefully: "I struck, and struck again, /And, growing still in stature, the high cliff /Rose up between me and the stars." As he tries to row away, the shape rises up higher. It will recede only when he rows back to shore. The fear he feels is not quick to dissipate; for "many days" the familiar shapes of nature in his mind—"trees... /sea or sky...colours of green fields"—are replaced with "huge and mighty forms that do not live /Like living men," which "moved slowly through my mind/By day, and were the trouble of my dreams."

It is important to note here, however, that these "huge and mighty forms" are not necessarily *sinister*—they are, perhaps, more precisely defined as *sublime:* strange, awesome, and preoccupying—as befits the products of an imagination whose enormous capabilities have been aroused by its own ability to direct nature's motion. That Wordsworth's movement both produces and prolongs this exhilarating effect suggests that he takes, to some degree, an active role in frightening himself. Alan Richardson emphasizes Wordsworth's "active participation in the illusion," suggesting that he is excited by his ability to summon a monstrous black shape out of nowhere, and tries, although eventually too frightened to continue, to make it bigger.[7] It is true, as Richardson maintains, that the boy's feeling disturbed by the "huge and mighty forms" does not imply that "his animation of nature... backfires." However, I would argue that although there is undeniable exhilaration and excitement in the Stolen Boat episode, it does not come from the child, who at the time is merely frightened and confused. It is the adult Wordsworth who is inspired by the remembrance of his mind's precocious power to perceive "unknown modes of being," and who transmits these feelings into the poetry. Wordsworth's elation and gratitude are indicated by the effusive, passionately grateful apostrophe to the "beings of the hills,/And ye that walk the woods and open heaths/By moon or star-light" that immediately follows the Stolen Boat scene. Wordsworth thanks nature for allowing him to glimpse "huge and mighty forms," only here they are "high objects...eternal things... /life and Nature." The "pain and fear" that he has felt is necessary to the recognition of the human imaginative capability—the "grandeur in the beatings of the heart." Geoffrey Hartman comments astutely on this idea: "Nature—for Wordsworth... is a haunted house through which we must pass before our spirit can be independent."[8] With nature's assistance, Wordsworth begins to guide himself by the steady, yet vital motion of his own heart, as he was guided by the motion of the river—he will overcome his human waywardness and gain the focus, the self-awareness, and the imaginative power that will allow him to be a poet, a creative being.

In the Ice-Skating scene, which in the 1799 *Prelude* immediately follows the Stolen Boat, young Wordsworth incites the whole world to joyful movement. In the Egg- and Boat-Stealing episodes, it is the movement of nature around the poet, or the way nature aids the poet's motion, that creates the memorable experience, but here Wordsworth's motion is the catalyst. When he skates to a sudden stop, he imagines, in his dizziness, that "the earth had rolled/With visible motion her diurnal round!" His imagination allows him to chase the stars and observe the motion of the earth. The "solitary cliffs" and "shadowy banks" wheel by *him*—not, as physics would deem more likely, him by *them*. Wordsworth's sudden stop has, in his mind, set the whole landscape in motion with him as a center. As Richardson notes, "the boy's activity speeds up the earth's motion and makes it appear instinct with

life, and to 'roll' by means of a visual hallucination... the boy deliberately, and repeatedly, brings about the desired illusion."[9]

This is an important point: in these episodes, Wordsworth does not only create motion in the natural landscapes around him—he creates *human* motion, in the sense that the natural world moves in reaction to the poet's own feeling. When he is ice-skating, Wordsworth is giddy with joy, so the motion of the world is giddy too, and all-encompassing—the enormous happiness the boy feels creates an illusion of huge, spinning movement, as though the entire earth were pirouetting and leaping for joy. In the Stolen Boat scene, Wordsworth feels fearful of the dark and guilty, which produces both the guilty motion of his rowing and the frightening, looming motion he perceives in his surroundings.

In Part Two of the 1799 *Prelude,* Wordsworth recounts a childhood memory in which the harmonious, teacher/pupil relationship between himself and the natural world, and also the increasing power of his imagination and his ability to illuminate the landscape with his poetic vision, are reflected in a juxtaposition of images of movement and stillness. In this episode, Wordsworth and his Hawkshead companions rent horses, "anxious for one day at least/To feel the motion of the galloping steed," and ride to the ruins of Furness Abbey, "a journey too distant far/For any cautious man." There are powerful images of motion in this scene; namely, the horses galloping and the boys trying, as a sort of gleeful challenge, to make the journey in the allotted time. Wordsworth's horse-riding is a natural act that suggests the harmony and intimacy between him and nature. However, his excitement at the opportunity to direct the "galloping steed," at the degree of control he has over an animal that is a part of nature, mirrors his growing recognition and confidence in his ability to shape the world around him with his creative mind. The boys' high-speed ride through the abbey dominates this scene: "With whip and spur we by the chantry flew/In uncouth race...Through the walls we flew/And down the valley... /In wantonness of heart, through rough and smooth/We scampered homeward." The boys fly and scamper, more like birds and animals than people; furthermore, they are flying and scampering on horses—their movement is in this way doubly connected to nature. These are some of the most wild, joyful lines in the poem; it is this natural motion—fast, bounding, and uninhibited—that is central to Wordsworth's experience and that reflects the development of his imagination.

However, in this scene, images of stillness and calm cannot be ignored; in fact, here, motionlessness plays an important role in developing Wordsworth's awareness of the harmoniousness of his relationship with nature, even as Wordsworth's passionate motion indicates the growth of his poetic mind. In this way, the juxtaposition of motion and stillness in this scene suggests a flowering of what Geoffrey Hartman calls Wordsworth's "double consciousness"; as Hartman observes, "nature-consciousness, joined to an answering self-consciousness, is the 'incumbent mystery' from which Wordsworth's poetry springs."[10] In the Furness Abbey episode, Wordsworth exhibits a vivid, spiritual awareness of his surroundings, a "nature-consciousness," when both the landscape and he are still. Having dismounted and left his horse to graze, he admires the "holy scene" of the forest which has overrun the abbey ruins. It is "silent and motionless alike," "Left by the winds that overpass the vale... /In more than inland peace." Later, he joyfully senses the presence of nature's "still spirit" as he "breathes," or stops his horse to rest. Perhaps the most beautiful and subtle image of stillness in this episode is Wordsworth's memory of having been in the abbey ruins before and hearing the song of one unseen wren—a faint sound that one would have to be still to hear—and thinking it sang "so sweetly" that he was tempted—and is still tempted, as he gallops past—to "live...for ever there, /To

hear such music." Indeed, living forever in the abbey ruins is yet another sort of temporal and physical motionlessness.

These images of motion and stillness are juxtaposed frequently: no sooner has Wordsworth described the "more than inland peace" of the scene than he is "remounted" and flying through the ruins. He remembers the wren's song and the holy peace to which it had inspired him, as he makes a bounding "circuit... /Through the walls... /and down the valley... /In wantonness of heart." He is aware of nature's "still spirit" not only as he rests his horse, but as he gallops homeward, beating "with thundering hoofs the level sand." Because he is alternately moving and still, the imagery of motion gains a new level of complexity here—he is not the self-absorbed ice-skater, imagining the world spinning around him; nor is he the precariously balanced egg-stealer, seemingly supported by the wind. Rather, in this episode, imagery of stillness suggests the harmony Wordsworth feels with nature, his reverence for its holiness, and the moments when, even as a child, he stops in the midst of some "boisterous race," struck by his love and gratitude for nature's "still spirit." At the same time, imagery of motion indicates that his imagination is working intensely and actively shaping the experience—the contrast of Wordsworth's confident, galloping motion to the stillness of the natural scene suggests that his imagination is the dominant "spirit" of the two. Through images of motion and stillness, we see Wordsworth's "double consciousness" developing. Much of his wisdom lies, to use one critic's phrase, in this "stillness which does not deny movement, and movement which contains stillness."[11] Here, he is grateful and reverent toward nature; he is inspired by nature to ever quicker and more graceful movement. However, he asserts his power and independence. As he says, "In happiness my blood appeared to flow/With its own pleasure" (my italics). When nature moves, it moves with his pleasure, according to his will, and takes its beauty from his imagination.

Wordsworth's portrayal of children, especially of himself as a child, at once changes and stays the same in the 1799 *Prelude* and the Intimations Ode. The difference, of course, is what happens to the children as they get older—the child in the 1799 *Prelude* spends his tumultuous first years in a sort of unthinking, but passionately *feeling* communion with nature, yet as he grows begins to see his interactions with nature as formative experiences essential to the maturation of his creative power. In the Ode, children begin to lose their intimate connection—not with nature, but with immortality—as soon as they are born, becoming more and more thoroughly ensconced in the "prison house" of earthly life. The similarity, then, is the connection—in both poems, babies have the strongest, most elemental connection with a spiritual presence, whether it be natural or immortal. In the 1799 *Prelude,* Wordsworth emphasizes the motion of nature that, with its "awakening breeze," solicits this connection. The "virtue which irradiates and exalts/All objects through all intercourse of sense," that ensures the baby's connection with the natural world, is reminiscent of the "motion and... spirit, that impels/All thinking things, all objects of all thought, /And rolls through all things" in *Tintern Abbey.*[12] The educative, inspiring spirit of nature is a sort of motion; the universe is an "*active* universe."

The last lines of the 1799 *Prelude* contain what almost amounts to a hymn to this motion of nature and its central role in the formation of the poet's own "plastic power," his ability to shape natural scenes with his imagination and emotions. This "forming hand," he says, was in his youth "at times/Rebellious... at war/With general tendency" but for the most part "Subservient strictly to the external things/With which it communed." In other words, although the poet's "obeisance... devotion... /and... transport" rely on his own "auxiliar light" and its power to enhance scenes of natural beauty, Wordsworth never forgets the essential role nature has played in the development of this poetic vision. As he says, nature is

constantly moving, and has educated him with motion:

> From Nature and her overflowing soul
> I had received so much that all my thoughts
> Were steeped in feeling. I was only then
> Contented when with bliss ineffable
> I felt the sentiment of being spread
> O'er all that moves, and all that seemeth still...
> O'er all that leaps, and runs, and shouts, and sings,
> Or beats the gladsome air, o'er all that glides
> Beneath the wave, yea, in the wave itself
> And mighty depth of waters.

Wordsworth is "contented" only when he is a part of the universal motion that, here, is the dominant characteristic of nature. He receives "so much" inspiration, edification, and imaginative power from blending, or "spreading" himself into the motion of nature and from moving harmoniously with nature. Indeed, his imagination dominates nature to the end—Wordsworth has the godlike power to spread himself over nature, to put himself into every part of nature. However, as a baby, he needed the welcoming, awakening, gentle movement of nature to begin his journey toward the sort of imaginative power that allows him to cultivate his "auxiliar light," to "spread o'er" the myriad moving parts of nature.

Images of motion in the 1799 *Prelude* suggest the harmonious relationship between the poet and the natural world; the motion of nature inspires and instructs the young Wordsworth, allowing him to build his creative power and move toward a mature poetic vision. Wordsworth's ability to shape natural scenes or to enhance nature by imagination, is also frequently reflected in the 1799 *Prelude* by his own joyful, powerful, or purposeful motion. In his magnificent "Ode: Intimations of Immortality," written several years later, Wordsworth has lost confidence both in nature as a course of inspiration and in his own auxiliar light. Images of motion, which are central in the Ode as they are in the 1799 *Prelude,* undergo a corresponding change.

To do justice to the complexity of the Intimations Ode, it is crucial to recognize that the "preponderant mood" of the poem is neither "joy and affirmation," as several critics have claimed, nor "regret and diminishment."[13] I would argue that in the Ode, the principle concern—that the freshness of youthful perception inevitably fades, taking with it creative power—is never satisfactorily alleviated. However, I do not intend to take sides in the debate over whether or not Wordsworth succeeds in reassuring himself that he has retained an adequate number of "shadowy recollections," or even if it were Wordsworth's intention to seek this reassurance. The Intimations Ode ends, indeed, with Wordsworth proclaiming his gratitude for "the human heart" and convincing himself that his memories of childhood bliss, combined with being able sedately to join the revelry of nature "in thought," are ample recompense for the "something that is gone." However, images of motion in the poem support a reevaluation of this compromise. Throughout, the language of the Ode regularly suggests a lack of motion, an impaired motion, a backwards motion, or a forced or unwilling motion. The many images of motion in the Intimations Ode fit loosely into two categories: first, the poem depicts the human journey, or movement, from east to west, childhood to adulthood, innocence to experience, awake to asleep, clear-sighted to blind. Of course, this movement is made reluctantly, and the language of the Ode consistently reinforces this reluctance. The second type of motion prominent in the Ode is the poet's motion away from a childhood love of nature and toward a mature recognition that earth and nature are not all-in-all, that he has come to nature from immortality. This motion is also made with reluctance and sadness, even though it is necessary to gain the consolation of recognizing that one has an immortal soul. It is useful to think of both of these types of motion as a hunt or a search; as Wordsworth moves east to west, from being a child, able to see the world "Apparell'd in celestial light," to being an adult, to whom the light has faded

"into... common day," he searches for a way to prevent the increasing blindness and to see the celestial light again. As he moves toward the recognition that the natural world is not the source of his poetic vision, or imaginative power, he hunts for the actual source, and ostensibly finds it, in his immortal origins. However, both hunts are, to a significant degree, ineffective: Wordsworth's attempts to see and interact with the natural world as he did as a child, far from succeeding, emphasize his reluctance, even inability, to move forward. The recognition that he has an immortal soul does not provide adequate consolation for Wordsworth; he seems as uneasy a denizen of the immortal world as he does of the natural world.

In the 1799 *Prelude*, as I have shown, motion is also central—in this case, to Wordsworth's interaction with the natural "ministries of fear and love." Motion in the 1799 *Prelude* is almost always purposeful and in the right direction, viz., towards the edification and inspiration of the poet. In the Intimations Ode, however, natural motions, and the poet's motion, take a course that seems at once *more* and *less* "natural," in the sense of "the way things really are" or "the way things have to be," than the motion in the 1799 *Prelude*. It is true that motion from childhood to adulthood, from east to west, is the motion that every human is constantly making, while the strange images of motion in the *Prelude*—mountains rising up out of nowhere, the earth rolling with "visible motion her diurnal round"—seem like dreams and fairy tales. However, in the Intimations Ode, the poet makes east-west motion unwillingly, and searches fruitlessly for a way to stop it, while in the 1799 *Prelude,* motion is usually "giddy" or a "boisterous race" full of joy and health. The poet is often the center of motion in the 1799 *Prelude,* unwittingly exerting his creative power to inspire motion in his surroundings that is harmonious with his own. Even if the motion he creates in nature occasionally frightens him, it is recollected joyfully by the adult Wordsworth as the first stirrings of his poetic imagination. In the Ode, there is a division between the motion of the poet and the motion of everything else; he cannot move toward the immortal world, and he is no longer satisfied with the motion of nature. Instead of having the ability not only to move with, but to be instructed by and to some degree control, the movements of nature, as in the 1799 *Prelude,* Wordsworth in the Intimations Ode can only move westward at odds with everything around him, behind him, and beyond him. His search for a new source of poetic inspiration has uncovered a realm of existence that seems completely alien to him, from which he is cut off by his mortality, in which and toward which he cannot move comfortably.[14] To see his final decision (to consider this unstoppable motion worthwhile in that life experience is gained by it) as a complete resolution of all the terror and sadness in the Ode, is equivalent to supporting unequivocally the "fortunate fall" theory. However, the mature, genuine happiness of Wordsworth's final affirmation in the Ode should not be discounted either. Consequently, the most complete analysis of the Intimations Ode seeks in this paradox complexity, not reconciliation.

The first lines of the Ode express the poet's worry that he is no longer able to see a certain type of otherworldly beauty in his natural surroundings. In the first two lines, he names a number of things that have been affected by this partial blindness: "meadow, grove, and stream,/The earth, and every common sight." It is this list that arguably gives the first evidence of unnatural motion in the Ode. A list has a motion of its own; it progresses from beginning to end and often has some sort of order, or recognizable progression. Wordsworth's list, however, makes an astronomical leap from singularly named, small pieces of scenery: "meadow, grove, and stream," to huge, all-encompassing territories: "The earth, and every common sight." The entire stanza is affected by this enormous jerking motion. It is as if Wordsworth

suddenly realizes that he can't control the blindness that is affecting him—whatever it was that "pass'd away" has left everything he sees, and since it affects the whole earth, everything it is possible to see.

Frequently in the Ode, Wordsworth searches for natural objects and phenomena that retain the celestial beauty they had in his childish perception. The search is fruitless; nothing successfully meets his criteria, as he admits at the end of the second stanza. Moreover, his descriptions evoke a natural landscape that abounds with purposeless, cyclical motion. For example, the rainbow "comes and goes," the rose is "lovely," but it, too, is doomed to bloom and die. Wordsworth is depressed by the ephemerality of nature. He wants to console himself with something solid that he can see all the time. The moon is another potentially reassuring natural object. The moon "doth with delight/Look round her when the heavens are bare." The moon, it seems, can do what Wordsworth cannot, at least as an adult: "look round her" and see celestial light. However, as David Venturo points out, the moon does not create its own light, but reflects the light of the sun; moreover, the degree of its reflection waxes and wanes, making it ephemeral like the rose and the rainbow.[15] Also, the moon can only "look round her" successfully "when the heavens are bare," which they often are not in the rainy north of England. These direct and implicit qualifications suggest back-and-forth, indecisive, searching motion, and create a mood of confusion and dissatisfaction. Wordsworth's search to find natural objects that still retain the beauty they had when he was a child is thus far unsuccessful.

It is important to note the last two lines of the second stanza, in which Wordsworth makes the most definite statement of the poem so far: "But yet I know, where'er I go,/That there hath pass'd away a glory from the earth." He *knows* this; whereas before, he admits that the world only *seemed* to be "Apparell'd in celestial light." He carries this sad knowledge with him "where'er [he] go[es]." His search for celestial beauty in nature is hindered by the knowledge that something beautiful and essential is gone from his life. It is obvious from the first two stanzas of the Ode that images of motion, perhaps more than any other device, are effective in transmitting the poet's feelings of loss and confusion.

In the fourth stanza of the Intimations Ode, the repetition of personal pronouns powerfully expresses a division between the poet and nature and the poet's attempt to force himself back into his old relationship with nature once he has recognized that "there hath pass'd away a glory from the earth." The fourth stanza begins with a crowd of *I*'s unusual in number even for Wordsworth:

> Ye blessed creatures, I have heard the call
> Ye to each other make; I see
> The heavens laugh with you in your jubilee;
> My heart is at your festival,
> My head hath its coronal,
> The fullness of your bliss, I feel—I feel it all.

There are six first-person pronouns in as many lines—Wordsworth affirms his presence extremely aggressively here, and also in the repetitively insistent line that comes soon after: "I hear, I hear, with joy I hear!" One is led to wonder why he feels the need to force himself into a "sweet May-morning" in a beautiful meadow when in other poetry he so often exhibits an easy intimacy with nature. One scholar suggests that the personal repetition in these lines is a result of Wordsworth's joy in recognizing anew the pervasive "animating power of nature," and that by declaring his presence in the scene he reiterates "his sense of oneness with his surroundings by affirming communion with its voices."[16] However, in many of Wordsworth's other important moments of communion with nature, he does not rely on repetition to make his presence known. In the 1799 *Prelude,* Wordsworth is arguably the physical, spiritual, and emotional center of every one of the "spots of time," but there is no string of *I*'s to rival this one in the Intimations Ode.

Furthermore, these lines also contain three *your*'s, two *ye*'s, and a *you*, allowing every *I* to have a *you*. Thus, a division is made between the poet and his surroundings; he is *I* and the landscape is *you*. There is no *we*. The poet's search for a way to merge smoothly with nature as he once did has failed; he must assert himself histrionically, his motion impaired by sadness and uncertainty, by the "something that is gone."

In the fifth stanza, the poet begins to answer the question he asks in the first four: "Whither is fled the visionary gleam?/Where is it now, the glory and the dream?" E.D. Hirsch affirms that the motion "of the sun round the earth" is the "main image" of the fifth stanza, if not the "controlling image of the whole poem."[17] Indeed, birth is a sort of sunrise here, because the soul, "our life's star," rises when we are born; we are born "trailing clouds of glory" like morning sunbeams. We grow up moving "daily further from the east," in childhood able to "behold... the light, and whence it flows," and finally, in adulthood, we see it "die away." Ostensibly, this motion is reassuring just as the rainbow and the rose are, because every sunset prefaces another sunrise, symbolizing "nature's eternal cyclicity and man's unbroken spiritual history."[18] However, for Wordsworth, whose primary concern so far has been his increasing inability to see nature the way he could when he was a child, the cyclical motion of the sun around the earth is not a comfort. Like every human being, he will live his adult life "in the light of common day" and die without another chance to see the world beautified by the light of a newly risen soul. The fifth stanza is the one in which we see the poet most clearly making a "natural" motion—from east to west, young to old, birth to death—with extreme reluctance. Importantly, the famous "shades of the prison-house" line in stanza five is a depiction of the natural world that is unquestionably negative for the first time in the Ode. To Wordsworth, the earth is a prison now. Christopher Salvesen states it well: the poet's "pure and illimitable mind," comprised of his recollections of immortality, "feels human existence and human substance pressing in upon it," and he stops searching for fulfillment in earthly things.[19]

The eighth stanza of the Intimations Ode can be seen as a sort of climax, in which all the conflicting desires, ambiguous fears, and unwilling motions of the poem so far come to a head. Wordsworth has described the actions of six-year-old Hartley Coleridge, on whom the "shades of the prison-house" are already closing; the child tries to imitate the adults he sees around him, indicating his alienation from his immortal origins. Wordsworth begins the eighth stanza by addressing the child in a deceptively congratulatory manner. "Thou, whose exterior semblance doth belie/Thy soul's immensity," ostensibly suggests that the child is simply soulful, or wise and imaginative. However, the image of a huge soul immobilized in a tiny body that *belies*, or contradicts, the size of that soul, is oppressive. Furthermore, the body is analogous to the prison-house that closes around the "growing Boy." This image of a soul being buried alive or imprisoned in the child's body corresponds with one of Wordsworth's most unsettling images: the child's conception of the grave as "A place of thought where we in waiting lie," without "the sense or sight...or the warm light." Wordsworth removed these lines (121-124) after 1815, at Coleridge's urging. They are, indeed, grotesque, as is the idea of an immortal soul gradually withering away in a gifted but oblivious being whose "whole vocation/Is endless imitation." However, it is important not to discount the celebration of the child's connection to the immortal world that may also validly be read in the opening lines of stanza eight. The crucial recognition here, for the reader, is the predominant mood of deep ambiguity, indecisiveness, and apprehension; the results of Wordsworth's search for a new source of poetic vision are troubling him. These feelings are expressed through several complex and paradoxical images that suggest impaired or oppressed motion, while

impeding the motion of the poem toward reconciliation or relief.

The multiple and frequently conflicting meanings in the eighth stanza create an atmosphere of growing ambivalence and confusion and an increasing sense of forced, halting motion. Here, the child is "haunted for ever by the eternal mind," although the continued presence of the eternal mind is supposedly the object of Wordsworth's search—why is the child, here, "haunted" by intimations of immortality and not 'blessed' by them? Furthermore, Wordsworth has made it clear that intimacy with the eternal mind does not, and in fact *cannot* remain "for ever" in the prison-house of earthly existence. Perhaps he means 'forever' as in 'constantly.' The child, then, is 'constantly' 'haunted' by the immortal world and the connotations of this perpetual haunting are disquieting. This haunted child begs comparison with the similarly horrified young Wordsworth in the 1799 *Prelude,* whose boat-stealing adventure leaves him for "many days" with "a dim and undetermined sense/Of unknown modes of being." In this instance, as I have noted above, the adult Wordsworth looks back on the experience as being beneficial because it (then) strengthened his connection with nature and (now) reassures him of his undiminished imaginative power. The difference in language between the two poems is striking. In the 1799 *Prelude,* Wordsworth has a "dim and undetermined sense" of whatever it was that frightened him. In the Intimations Ode, the child is unambiguously "haunted." In the 1799 *Prelude,* the implication is that the child is thinking deeply about his experience. The "huge and mighty forms," as exhilarating as they are disturbing, move "through" his mind, shaping it and sharpening it. In the Ode, the other-worldly "sense" seems forced on the haunted child. He is, indeed, literally burdened with it: he is the "Mighty prophet" "On whom these truths do rest." Finally, the 1799 *Prelude*'s "many days" versus the Ode's "for ever" indicates a desperation of feeling in the Ode that the 1799 *Prelude* does not share. In the Intimations Ode, it is as if Wordsworth wants the childhood haunting to go on forever, to assure him of his connection with the eternal mind, but at the same time balks at the oppressive thought of being "haunted for ever" by the immortal world, which is so alien to the "beings of the hills... that walk the woods and open heaths" that occasionally troubled his dreams in the 1799 *Prelude.*

Stanza eight continues with more ambiguous images that evoke reluctant, forced motion and indicate that Wordsworth is ambivalent about the results of his search. As an adult, Wordsworth observes, he has been "toiling all [his life] to find" the "truths" which "rest" upon the child. He describes the search for his exalted immortal origins as "toil," which connotes both an unwillingness to make the search and a feeling that the search is a lowly and even a shameful task. For all his "toil," however, he is like all adults, "In darkness lost, the darkness of the grave." In an allusion to Milton, Wordsworth likens the "immortality" of the child to the Holy Spirit brooding over Chaos in *Paradise Lost:* "Thou, over whom thy Immortality/Broods like the Day, a master o'er a slave, /A presence which is not to be put by." The ambiguity of this image abides in its reference to *Paradise Lost,* in which the "brooding" of the Holy Spirit is defined by the *Oxford English Dictionary* (OED) as sitting or hovering, "with outspread cherishing wings."[20] Milton's Holy Spirit "satst brooding on the vast Abyss/And mad'st it pregnant"; the Holy Spirit creates order from chaos.[21] Miltonic brooding is beneficial, then, as is the child's connection with the immortal world that infuses his perception with "celestial light." However, Wordsworth likens the brooding of immortality over the child to that of a "master o'er a slave, /A presence which is not to be put by." This brooding seems closer to another *OED* definition of the word, which was used in this sense by Wordsworth's contemporaries: "to meditate moodily."[22] Here, again, are conflicting images that suggest the weight of immortality and the oppression that the child must endure, and also the poet's exaggerated

reverence for the child and his undeniable, but "toiling," attempts to be like the child.

It is important to note that images of weight and oppression are associated with both the natural and the immortal world in the Ode; Wordsworth implores the child to stop imitating adults, not to "provoke/The years to bring the inevitable yoke," because "full soon" the child will feel the now "*earthly* freight" upon his immortal soul (my italics). The weight is now upon the immortal soul, not the child, as it is in the beginning of stanza eight, when the child's "exterior semblance" traps the soul inside it. Then, in the last two lines of the eighth stanza, the oppressive weight shifts suddenly back to the child: "and custom lie upon thee with a weight/ Heavy as frost, and deep almost as life!"

Stanza eight is a morass of conflicting images. There is weight upon the child and weight upon the soul; the weight of immortality is at once the positive, creative weight of the Holy Spirit, and the negative oppression of a master over a slave; the child is a slave, but also "glorious in the might/Of heaven-born freedom"; the child grows up so quickly that at six years old he is already forgetting his immortal origin, but images of weight and oppression slow the stanza's motion to a miserable crawl through "the darkness of the grave," into a "lonely bed" into which Wordsworth places not only the adult, but the child. Everything in this stanza is weighed down, moving slowly or not at all, except the painfully fast motion from east to west, from childhood to adulthood, that the poet is still searching for a way to slow down. Images of motion in this stanza indicate a multiplicity of imagery, ambiguity of theme, and confusion of feeling.

The closing stanzas of the Intimations Ode are Wordsworth's attempt to convince himself once and for all that his search for a new source of poetic inspiration and spiritual fulfillment has been successful. However, images of impeded and uncertain motion, and the often confusing and paradoxical motion of the poem itself, suggest otherwise. The tormented and dirge-like last lines of the eighth stanza, which lament the weight of earthly existence, "Heavy as frost, and deep almost as life!" are immediately followed by a grateful exclamation of "O joy!" that, coming where it does, jolts the poem out of the depths of despair and into the heights of elation. Wordsworth's suddenly feeling joy and complete comfort, as the result of the "something that doth live" in the "embers" of his mortality, is unconvincing considering the significant misgivings he has about immortality that are implied by the language and imagery in stanza eight. I would argue that he is not satisfied. He has not stopped restlessly hunting for a new source of imaginative power, and he has not entirely given up hope that he will somehow regain the poetic vision of his childhood.

Ostensibly, Wordsworth goes on to sing the praises of the intimations of immortality that he recalls from his childhood; he is deeply thankful for memories of "those obstinate questionings/Of sense and outward things,/Fallings from us, vanishings;/Blank misgivings of a Creature/Moving about in worlds not realized." However, there are several images of unnatural and unwilling motion in these lines which belie the notion that gratitude is all he is feeling. Wordsworth is thankful that his memories of immortality, his knowledge that he has an immortal soul, allows him to question the information he receives from his five senses, but he describes the natural world as "falling" away from him, and as "vanishing." These images are negative; they imply a separation of Wordsworth from the natural world that he doesn't want to happen or that happens involuntarily. Moreover, when he is immersed in his memories of immortality and separated from sensory perception, he is "Moving about in worlds not realized," he is a "Creature," not a person, and he is troubled by "Blank misgivings." In other words, he doesn't know how to move in the immortal world, he loses the "sense" that makes him human; the strangeness of the immortal

world and his unfamiliarity with it give him blank misgivings about being aware of it.

When confronted with the incomprehensible "High instincts" of the immortal world, Wordsworth's "mortal Nature/Did tremble like a guilty thing surprised." Interestingly, the "guilty thing" is a reference to *Hamlet*—Horatio describes Hamlet's father's ghost's reaction at being called back to Purgatory using the same phrase.[23] Wordsworth, then, likens the moments in which he is most vividly aware of the immortal world to a ghost being summoned back to Purgatory. This analogy encourages the view that he does not feel at home in either the natural or the immortal world. If he is a ghost in the natural world, he obviously doesn't belong in it. Ghosts are unnatural and immaterial; they can't connect with and move among material objects the way mortals do. Also, the reference unavoidably likens Wordsworth's intimations of immortality to a ghost's summons back to Purgatory, which is defined by the *OED* principally as "a place or state of temporary suffering [and] expiation."[24] If the immortal world is a sort of Purgatory here, it is not only a place of suffering, but a place in which one's soul resides *temporarily*—invalidating it both as a source of comfort and of permanence, which is exactly what Wordsworth will say that it is a few lines further down: the "shadowy recollections" of the immortal world are no less, to him, than the "master-light of all our seeing." Furthermore, why does Wordsworth's "mortal Nature" feel "guilty" when confronted by "High instincts" or memories of immortality? Perhaps the guilt comes from abandoning nature as a source of poetic inspiration; perhaps it comes from having forgotten his immortal origins in the first place. Perhaps, even, Wordsworth feels guilty because he wants to regain his childish intimacy with nature, knows he cannot, and so is settling instead for the "shadowy recollections" or the "fallings" and "vanishings" of which he is, more than anything, afraid. None of these explanations is entirely provable; all, however, are plausible. There is, then, a significant confusion of imagery here, which comes *after* Wordsworth arrives at the decision to be contented by the poetic inspiration he gets from his memories of the immortal world. However thankful he says he is, Wordsworth is still thwarted in his search for untempered fulfillment and inspiration from the immortal world.

The Intimations Ode ends happily. Wordsworth's assurance that he has found fulfillment and comfort in the "faith that looks through death" and in the "philosophic mind" is never stronger than in the last two stanzas of the poem. However, even here there are inconsistencies that suggest that his positivity cannot fully overcome the sadness, fear, and ambivalence that are so vividly expressed earlier in the poem. Strong as it is, the comfort he feels comes from remnants: "We will grieve not, rather find/Strength in what remains behind." His thoughts are "soothing," but they necessarily "spring/Out of human suffering." He is grateful for his mature, philosophic mind, but has already exclaimed with much fervor that the child is the "best philosopher." In the last lines of the Ode, he expresses gratitude for his "human heart," and finds joy in "the meanest flower that blows." These images have nothing to do with immortality; quite the opposite in fact. Arguably, Wordsworth here returns to the place from which he began. He is searching for, but cannot find, the same inspiration and comfort as an adult in the natural, human world that inspired him as a child.

As I have argued, there is an important change in the depiction of movement from the 1799 *Prelude* to the Intimations Ode. Motion in the 1799 *Prelude* is purposeful, uninhibited, and powerful, and motion in the Ode is searching, confused, and irresolute. Because images of motion are predominant in both poems, the mode of their representation has significant thematic effect. In the 1799 *Prelude,* these images reflect the poet's harmonious movement with nature toward the empowerment of his imagination. In the Intimations Ode, images of confused

and oppressed motion, and the poet's unsuccessful searching for a reconnection with the natural and/or immortal worlds, contest the claim that the poem comes to a complete resolution. I have addressed the way these changing representations of movement speak to the significance of Wordsworth's spiritual shift from a joyful self-centered pantheism in the 1799 *Prelude* to the more somber, self-abnegating conception of a preexisting immortal soul in the Intimations Ode. He does not dally with the idea of immortality only to return unchanged to his habitual reverence for "rocks and streams." In fact, Wordsworth's later poetry continues down the path toward traditional religious orthodoxy, never revisiting the near nature-worship of the 1799 *Prelude* and *Tintern Abbey*. However, it is important to recognize that these recollections of immortality and memories of a childhood vision illuminated by "celestial light" never give Wordsworth the complete fulfillment, the euphoria, and the profound self-assurance that he enjoys in the early poetry. Recognizing that images of motion in the Intimations Ode permanently lose the purposefulness, harmoniousness, and educative power that they have in the 1799 *Prelude* supports a reading of the Ode as indicative of serious and largely irresolvable problems in Wordsworth's thought.

NOTES

1 This and all further citations from the 1799 *Prelude* refer to: *The Prelude, 1798-1799*, ed. Stephen Parrish (Ithaca: Cornell University Press, 1977) 43-67.

2 This and all further citations from the "Ode: Intimations of Immortality" refer to: *Poems, in Two Volumes, and other Poems, 1800-1807*, ed. Jared Curtis (Ithaca: Cornell University Press, 1983) 269-77.

3 Stephen Gill, *William Wordsworth: A Life* (Oxford: Oxford University Press, 1990) 162.

4 Jonathan Wordsworth, "The Two-Part *Prelude* of 1799," in *The Prelude: 1799, 1805, 1850* (Norton Critical Edition) ed. Jonathan Wordsworth, M.H. Abrams, and Stephen Gill (New York: W. W. Norton, 1979) 584.

5 *Lyrical Ballads and Related Writings*, ed. William Richey and Daniel Robinson (New York: Houghton Mifflin, 2002) 392.

6 Gill 162.

7 Alan Richardson, "Wordsworth at the Crossroads: 'Spots of Time' in the Two-Part *Prelude*." *The Wordsworth Circle* 19 (Winter 1988): 16.

8 Geoffrey Hartman, introduction, *The Selected Poetry and Prose of William Wordsworth*, by William Wordsworth (New York: New American Library, 1970) xi.

9 Richardson 16.

10 Hartman xi.

11 John Jones, *The Egotistical Sublime: A History of Wordsworth's Imagination* (London: Chatto & Windus, 1954) 68.

12 *Lyrical Ballads and Other Poems, 1797-1800*, ed. James Butler and Karen Green (Ithaca: Cornell University Press, 1992) 116-120.

13 E.D. Hirsch, *Wordsworth and Schelling* (New Haven: Yale University Press, 1960) 152.

14 George McLean Harper elaborates usefully upon Wordsworth's conception of the immortal world: "It is a surmise, nothing more, that the excellence of childhood may be an inheritance from a previous and presumably superior state of existence. This is...novel to [Wordsworth]...It is connected with no other of his writings. It is alien to his mind. He habitually poetizes the facts of nature and human experience." *William Wordsworth* (London: John Murray & Co., 1923) 125-6.

15 In conversation, 10/28/03.

16 Alan Grob, *The Philosophic Mind* (Columbus: Ohio State University Press, 1973) 236.

17 Hirsch 161.

18 Hirsch 161.

19 Christopher Salveson, *The Landscape of Memory: A Study of Wordsworth's Poetry* (London: Edward Arnold Publishers, 1965) 116.

20 "brood, v." *The Oxford English Dictionary* Online. (Second ed) 1989. Definition 5.

21 John Milton, *Paradise Lost*, in *The Works of John Milton*, ed. Frank Allen Patterson (New York: Columbia University Press, 1931) 9.1.21-2.

22 "brood, v." The *OED* Online. Definition 7.

23 William Shakespeare, *Hamlet*, in *The Oxford Shakespeare*, ed. W.J. Craig (New York: Oxford University Press, 1919) 1008.1.1.148-9.

24 "purgatory, n." The *OED* Online. Definition 2.

Student Experiences and Interpretations of Teacher-Student Relationships

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Abstract

This study analyzes the experiences of successful high school students in their interactions with their teachers. The results are based on intensive interview data collected from freshmen students attending a competitive four-year state college. The majority of interviewees were Caucasian and the sample of 12 consisted of six male and six female students. The findings of the study conclude that although they encountered negative teacher-student relationships, these successful students had high school careers during which they were given opportunities to develop academically and to feel cared for and supported. Using Randall Collins's concept of interactional rituals, one can conclude that the positive experiences which dominated the educational careers of these students not only outweighed their negative experiences, but also gave these students a sense of self confidence which made them more resilient in handling negative academic experiences. In addition, weaknesses of the study as well as implications for future research are discussed.

Introduction

Literature Review and Rationale

Researchers in the fields of sociology and social psychology of education have spent considerable time and resources exploring the relationships between teacher-student relationships/classroom interaction and student achievement and attitudes. Overall, the literature points to the integral role that teacher-student relationships play in determining a student's educational experiences. Burnett (2002) cites research which suggests that students indicate a desire for positive relationships with their teachers and that caring and encouraging relationships are associated with more positive attitudes toward school as well as greater academic engagement. Furthermore, Miller (2000) concludes that positive teacher-student relationships were strongly associated with students being on track to graduate high school within five years. This association was found among high school freshmen regardless of the student's race, gender, economic background or prior achievement (Miller, 2000: 5).

Also, an expansive study conducted by Burkam and Lee (2003) concluded that in schools where relationships between teachers and students are positive, students were less likely to drop out. This study also accounted for factors related to a school's organizational structure while analyzing dropout rates. Burkam et al. concluded that "the impact of positive relations, however, is contingent on the organizational and structural characteristics of high schools," including the school population size (Burkam & Lee, 2000: 390). This study concluded that the anonymity and other organizational disadvantages that arise from large student populations tend to reduce the benefits of positive teacher-student relationships in reducing dropout rates.

However, despite the benefit of positive teacher-student relationships for academic engagement and positive attitudes concerning

school, student experiences with teacher-student relationships vary in terms of a student's race and social class. A comprehensive study of the academic disengagement of African-American students in a predominantly affluent neighborhood outside of Cleveland concluded that among upper- and middle-class students, African Americans were more likely to be concerned with the quality of teacher-student relationships than Caucasian students (Ogbu, 2003). Concerns with inadequate and unequal teacher care and expectations were more likely to be reported by African American than Caucasian students (Ogbu, 2003). Pomeroy's (1999) interviews with excluded students (most of whom were determined by their teachers to be working class) revealed student attitudes similar to those of the African-American students in Ogbu's study. Excluded students in this study frequently discussed relationships with teachers as problematic, often expressing an unfulfilled desire for respect, concern, and support in their relationships with their teachers (Pomeroy, 1999). Similar findings were also reported by Brantlinger (1994), who found that low-income (and generally lower-achieving) students were more likely than their high-income (and generally higher-achieving) counterparts to be concerned with equity and support from their teachers.

Other studies have focused on the differences in teacher-student interactions between high- and low-achieving students. Although lower achievers are more likely to receive academic support and less pressure from teachers, students report that high-achieving students generally receive more emotional support in the classroom (Blote, 1995). Burnett (2002) and others (Dohrn & Bryan 1994; Marsh 1990; Craven 1991; Mueller & Dweck 1998) concluded that both positive ability and effort feedback are related to the perception of a positive classroom environment, yet positive-effort feedback fosters attitudes and behaviors more closely associated with academic success. All these studies clearly point to the vital role that teacher-student interaction (and inequality in such interaction) plays in determining the educational experiences and outcomes of students.

Clearly, the expansive body of literature on teacher-student interactions has emphasized the relationship between positive teacher-student interaction and student success and academic engagement. However, the literature also demonstrates that the quality of teacher-student relationships varies dramatically by race, social class, and student achievement. Given the importance of positive teacher-student interaction and the drastically unequal educational experiences noted in the research above, a greater understanding is needed of how and why differences in the quality of teacher-student relationships exist between academically successful and unsuccessful students. Hence, a better understanding of the educational experiences of successful students might help teachers to improve the educational achievement and engagement of all students regardless of their race or social class.

The aim of this study was to explore successful high school students' perceptions and interpretations of teacher-student relationships. Topics of study included student experiences and interpretations of the support, encouragement, respect, and academic feedback which they received from their teachers. Students' opinions about the characteristics that define teachers with whom they had positive relationships were also explored. This project generated detailed accounts of students' experiences in teacher-student relationships, including classroom support, encouragement, and feedback. The resulting information will contribute to our understanding of the role teacher-student relationships play in the educational process. By better understanding how teacher-student relationships influenced the educational experiences of successful high school students, teachers and other educational professionals can be better prepared to serve the educational needs of all students.

Methods

All participants in this study were full-time first-year (freshmen) students who lived on-campus at an academically competitive, mid-sized, four-year, state college. Because of their acceptance into a reasonably competitive college, I defined the students in this study as having been successful high school students. Of the 12 interviewees, six were male and six, female. One male respondent identified himself as Latino, another as African American, and one female respondent identified herself as Asian American. All other participants were Caucasian. Also, of the participants in the study, two attended high schools which would be defined by Lee and Burkam (2003) as "large" or "very large" schools.

Participants in the study were recruited on a volunteer basis. An unsuccessful attempt was made at utilizing a snowball sampling technique. Nonetheless, the sample did achieve a saturation point, as the topics and themes discussed in the interviews became repetitive. The researcher began by speaking with community advisers in the freshmen residence halls, asking them to forward information, via a phone message, concerning the project to their residents. However, all participants were recruited when the researcher spoke directly with students in the residence halls. The researcher described the project in detail to interested students so they were well informed about the nature of the research. Upon expressing an intention to participate, the interviewees signed up for a specific date and time to be interviewed.

Data were collected through in-depth interviews with the students. Interviews were conducted in a lab space provided by the Department of Sociology and Anthropology at the college. Interviews were tape recorded to enhance the researcher's ability to generate a more nuanced and detailed analysis of the collected data. The tapes then were transcribed and the transcripts were used thematically to code and analyze the data. Each student was interviewed once. Unfortunately, time constraints did not allow for follow-up interviews. All students were informed of the nature of the study and their rights as research subjects to terminate their participation at any time, to choose whether or not to have the interview tape recorded, and to keep their participation confidential. Before being interviewed each participant signed a consent form. (See Appendix 1.)

Analysis

The successful high school students in this study seemed to enjoy discussing their high school relationships. Of course some students took longer than others and required a little prodding in order to open up about their experiences, but the enthusiasm and warmth that characterized their recollections were clearly evident. Of particular interest in this study was the very natural way in which students responded when asked about the support they received from teachers with whom they had positive relationships. According to interviewees, such teachers were always available to give extra academic support or just "to shoot the breeze" during study halls, lunch, or before and after school. It is important to note, however, that taking the initiative to see teachers outside of class for academic support required a level of confidence and self-assurance on the part of these students.

The most poignant analogies made by students in describing teacher-student relationships were familial. Students described their high school teachers as father or mother figures or even as friends. One female interviewee encapsulated such responses when recalling her close relationship with her choir director during high school: "He doesn't have kids and he's not married so he treats us like his kids ... He would start giving us lessons ... very much fatherly advice." The readiness with which interviewees compared their teacher-student relationships to familial ties indicates the strong sense of caring and support they received from their social interactions with educators.

Another theme that emerged in the interviews was that when asked to think

of teachers with whom they had a negative relationship, interviewees had to pause for quite some time. Common responses to this question would include statements such as, "There was one teacher but it wasn't a big negative," or "I can't really think of anyone I had a particularly negative relationship with. I mean some teachers I just didn't like their teaching style or they weren't my favorite but I never really had a bad experience with any teachers." Very rarely did this occur when students were asked to think of teachers with whom they had positive relationships in high school. All these students fondly recalled their positive relationships.

Moreover, although some students mentioned that teachers with whom they had negative relationships favored other students, no student reported that a teacher simply did not care for her or him. This is clearly exemplified by one student's response when I asked her to recall any negative relationships she had with teachers during high school: "There were ones I didn't like... I might not have been one of their favorite students, but I didn't think they hated me or anything." Through such statements, students specified that although the experience may have been negative, such relationships did not define their high school careers. One female student after being asked if she could think of any other teachers with whom she had a negative relationship responded by saying, "I can't really think of anyone in particular. I mean I favored some teachers over other ones but besides that one teacher, I never really had any bad teachers." Thus, it is clear that although these students did have negative relationships with teachers, these experiences were not a prominent component of their educational experiences and did not inhibit their feelings of self-worth.

The strong role of expectations and self-fulfilling prophesies also characterized the interviewees' experiences in high school. Expectations to succeed academically were reported as coming from teachers, parents, and peers. A particularly noteworthy example of this came from a male interviewee who discussed the positive relationship he had with his high school calculus teacher: "He definitely encouraged me. I did pretty good in the class... He kept telling me he knew that I was capable because I was smart enough to do all the things we were doing... I think he just wanted to challenge us because it was an honors class, AP calculus. I guess that's what you're there for so it was expected." From this student's perspective, the importance of the instructor's confidence in the student's ability to succeed and the instructor's expectations that the student work hard both played a role in the student's success. Thus, the experiences of interviewees in this study support the premise that when others clearly express expectations for achievement and performance, students are more motivated and engaged in working to meet those expectations.

From the data collected in the interviews it became clear that the feedback students received from teachers differed significantly depending on whether or not the student had a positive or negative relationship with the teacher. Of particular interest to students was the clarity and thoroughness of feedback they received. Two female respondents exemplified this when speaking about their teachers. While describing a favorite English teacher one of them said, "She was really good about that kind of thing [giving feedback]. She would really explain her comments. She'd say you can improve on this or try writing this way and then [I'd] take that and incorporate it into her work. She really helped me to improve my writing style." The other interviewee noted that she appreciated the way in which her history and English teacher "gave a lot of feedback as to why [a particular grade was given]."

Also, the feedback received in positive teacher-student relationships was described as "constructive criticism." Such feedback highlighted both the strengths and weaknesses of the work students were producing. For instance, when asked about the type of

feedback they received in positive teacher-student interactions, student responses were consistent with the two following: "He was very straightforward about things... If you were having a problem with something he would say it directly—very constructive criticism—and if you were doing well he'd note on that too." "She called it praise and polish. She would give a positive thing and then she would [give] negative things... She would say how to make it stronger to build on what I already had."

Thus, overall, the criticism they received from teachers with whom they had positive relationships gave these students the sense that those teachers took a vested interest in their educational improvement. These experiences suggest that these teachers focused on the strengths of their students and built upon those strengths instead of "fixing" their weaknesses.

Conversely, the feedback students received from teachers with whom they had negative relationships was often unclear and the grades they received they regarded as arbitrary. For example, in describing the feedback she received from an English teacher one interviewee observed, "You just didn't know why it was wrong. You'd show it [a paper] to her and she'd just say 'Well, I don't think that this is your strongest paper.' I just felt it was very subjective... On a good day she may have given it a B but on that day she gave it a C+." Such feedback would cause students to conclude that they lacked control over the grades they received and also in taking actions to improve future performances.

The findings that are particularly interesting, however, are the responses some students made regarding other students who believed that the feedback given by a particular teacher was an "affront" or overly challenging. The successful students stated that they came to see this "harsh" criticism as, in fact, constructive and "really helpful." One student, for example, noted that her favorite teacher was known for yelling frequently, but "he yelled at everyone a lot so it wasn't like you ever felt that he was singling you personally out." Such findings may be explained by the fact that these students asserted that they were supported and cared for by their teachers. Thus, because they were able to achieve success in those courses and because they also felt well supported and cared for by their teachers, they were able to reconceptualize demanding criticism as an additional indication that those teachers truly had an interest in helping them to develop their talents.

Another interesting finding involved students' self-perceptions of challenges they faced in classes and the explanations they gave for those difficulties. All interviewees noted that positive teacher-student interactions largely depended on the ability of students to understand the ways in which teachers conveyed course material. Conversely, some of the students discussed the academic struggles they faced in courses with teachers with whom they had negative relationships. In almost all these accounts, students reported that they took a personal initiative to receive extra academic help from the teacher. This clearly suggests that the positive interactions, which overwhelmingly defined the educational experiences of these students, fostered academic confidence and self-assurance.

However, in some students' discussions of negative teacher-student relationships, an interesting perception of teaching and learning styles emerged. What is particularly interesting in their discussion of teaching styles is that although the students generally took personal responsibility for getting extra help, they did not completely place all of the blame upon themselves for having difficulty with the material. Instead, these students took into account the teaching methods of the instructor.

The following account given by one student describes such an experience: "When he taught, he taught concepts over mathematical ways of solving the problem and I think I might have enjoyed it better if he had put physics in terms of calculus. I really enjoyed

calculus and that was my strong suit... I would go to him for extra help a lot 'cause I really struggled with the class and he would explain it in the exact same [way]...[But] my English teacher, if you didn't understand what was going on she'd explain it in a different way...." Therefore, it seems that these students could find ways to perceive academic struggles not only as personal but in terms of their teachers' classroom practices/teaching styles.

Discussion

The findings of this study suggest that high schools are institutions which are well suited for middle-class students, where the social interactions between teachers and students provide students with opportunities to feel well supported and cared for. The accounts of these successful high school students emphasize that all students have negative teacher-student relationships over their high school years. However, a specific theoretical model proposed by Randall Collins is particularly pertinent to understanding the way in which successful students perceive these negative experiences.

Randall Collins's theory of interaction rituals focuses primarily on the "emotion-generating effects of rituals" (Turner, 2003: 438). Collins argues that human interaction is an exchange in which people essentially try to maximize the amount of emotional energy which they receive (Turner, 2003). Individuals tend to continue specific social interaction in which positive emotional energy is generated. However, "when interaction rituals require too much emotional energy without sufficient emotional payoff, then individuals gravitate to other interaction rituals where their profits are higher" (Turner, 2003: 441). This applies to the findings of both this study and previous studies of teacher-student relationships. Collins's theory of interaction ritual chains explains why students who do not receive adequate positive emotional energy from their interactions with their teachers tend to disengage from school and obtain positive emotional energy through participation in other social interactions. Conversely, students who gain positive emotional energy from their educational interactions tend to continue such interactions, thus increasing their academic engagement and performance.

The findings of this study support the theory that the positive emotional energy gained by successful students in their interactions with teachers overrides the negative emotional energy they experience in school. Hence, the self-confidence of these students allows them not only to succeed academically, but to create the "cultural capital" necessary to reconceptualize and handle negative experiences.

On the basis of these findings, I believe that additional research should focus on the ways in which at-risk or failing students perceive what their teachers believe to be constructive criticism. Based on the findings of this study, it is possible that because of the cumulative effect of negative experiences, failing students may perceive what their teachers see as constructive criticism in a much more negative light. Such knowledge would be helpful to teachers trying to accommodate to the differing pedagogical needs of students.

The findings in this report also emphasize the importance of focusing on a student's strengths as a means of fostering academic success and engagement. The educational experiences of students may be enhanced by further research into the concepts of multiple intelligences and multiple learning styles.

Indeed, the concept of multiple intelligences is gaining greater acceptance within the educational community. Schools are beginning to focus on the variety of ways in which students learn in order to provide educational experiences that will serve students with different learning styles. A seven-year study by Shearer (2004) highlights the importance of utilizing knowledge about multiple intelligences in order to enhance pedagogy. Such knowledge can effectively be used to design instruction and curriculum which builds on a student's particular strengths. Shearer's (2004) study concluded that well-developed multiple intelligence educational

programs can be used to educate teachers about misconceptions regarding intelligence and to use this knowledge better to develop "strength-based learning activities to enhance instructional practice" (Shearer, 2004: 147). The findings of this study support Shearer's (2004) premise that educational practices that build upon the strengths of students are effective in engaging and motivating students. Continued research, educational program development, and evaluation in this area of study are vital in order to improve the educational outcomes of all students.

In addition to the main themes which emerged in the interviews, three other interesting patterns were found. Particularly noteworthy were patterns which support the "looping" concept in education and gender-related differences in educational experiences. An understanding of such patterns by educators, school administrators, and policy makers is vital to making educational experiences open and available to a wide variety of students.

A particularly interesting pattern in the student accounts centered on the nature of the relationships students had with teachers with whom they took more than one class in high school. Of the total number of positive teacher-student relationships discussed in this study, approximately half involved teachers with whom students studied more than once. Conversely, none of the students took more than one course with a teacher with whom they reported having a negative relationship. Such findings may support the idea that teacher-student relationships and hence academic experiences of students can be enhanced when teachers and students are given the opportunity to build relationships over more than one school year or semester. The term "looping" is used in education to describe when schools are structured in this way so that students have each teacher for more than one school year.

Although the students in this study were primarily Caucasian and none attended urban schools, it can be argued that looping may be particularly beneficial to students attending urban schools. Because students in urban schools tend to have different life experiences from their teachers who are primarily middle class, looping may give teachers more time to develop a good working relationship with students. By so doing, teachers may be better equipped to meet the needs of students, enhancing their educational experiences. Of course, looping cannot be used as a universal means to improve teacher-student relationships. Obviously, a student who does not relate well to a particular teacher may not benefit and indeed may be disadvantaged by having that teacher for another course.

I am not arguing for looping as a uniform educational policy. However, I do believe that it is important to understand that a high percentage of the students' most positive teacher-student relationships reported in this study are with teachers they had repeatedly.

Another topic discussed in the interviews was whether students believed that their interest in a particular field of study was the result of relationships with their teachers or whether it arose out of their own inherent interests. Almost all interviewees reported that teachers played a role in the development of their personal interests, even if that role was deemed secondary to a "natural" interest in an academic subject.

However, females in this study were much more likely than males to report that a teacher directly influenced the development of their academic interests. This may be caused in part by the high value males in our society are taught to place on autonomy and self-determination. Females, on the other hand, are typically socialized to be more passive. The attitudes which result from such conditioning may cause women to develop a diminished sense of control over one's choices. Hence, the differences in expectations for gender roles may have played a role in students' perceptions of the impact of teachers on the development of their interests.

Furthermore, this study suggested that male interviewees were much more likely

than females to report that high school math or science teachers were among their favorites. Only two female respondents reported that a science or math teacher was among their favorites. When asked to speak in depth about favorite teachers, females mentioned their math and science teachers, but focused on those who taught other courses. Additionally, three of the females reported that math or science teachers were those with whom they had "negative teacher-student relationships" in high school. Two of the three female respondents reported that the relationship with this math or science teacher was negative because he did not explain the material in a way which they found comprehensible. However, no male interviewees reported having had a negative relationship with a math or science teacher. This finding is particularly pertinent, as the majors of participants in the study were very diverse and the male sample was not dominated by participants who were majoring in science-related fields.

This finding seems to indicate that females' educational experiences in math and science courses tend to be less positive than those of their male counterparts. The reports of the females in this study indicate that perhaps more research needs to be focused on the effects of using a variety of teaching methods in math and science courses in order better to engage females in math and science. This may have important implications in working for gender equality in education.

Of course all the findings discussed above require further research. Moreover, information about what spurred an interviewee's interest in a specific academic subject was not always forthcoming. As a result, these findings are not generalizable and must be explored in further detail before any strong generalizations can be made.

There are a variety of weaknesses in this study which must be noted. Because of its small sample size, this study's results may provide a detailed and nuanced, but not a generalizable, understanding of teacher-student relationships. Furthermore, students in the study were asked to recall experiences from high school after they had become first-year college students. As a result, the accuracy of their accounts may be flawed and additional educational and personal experiences in the year following their high school graduation may have caused bias in their interview responses. A final and extremely notable limitation of this study was that follow-up interviews could not be conducted as a result of time constraints. As a result, the researcher was limited in her abilities to gather more data from interviewees.

In conclusion, the high school experiences of participants in this project demonstrate the capacity of our educational system to provide an environment in which students can develop self-assurance and their personal talents. However, it is clear from the existing body of literature, including work by Ogbu (2003), Pomeroy (1999), and Blote (1995), that such experiences are not available to all students. Continued research, including studies that further explore student perceptions of constructive criticism and the effectiveness of strengths-based teaching practices, is vital in order better to understand and address educational inequalities. It is only through such knowledge and the concerted efforts of administrators, policy makers, and educators that we can begin to remedy these inequalities and offer an equitable education to all.

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APPENDIX 1: CONSENT FORM

Dear Student,

My name is Erin Blew and I am a senior sociology major at TCNJ. I am working on a senior research project under the advisement of the chair of the sociology department, Dr. Rebecca Li. The project focuses on student experiences and perceptions of teacher-student relationships in high schools. You have expressed interest in participating in this study. Before being interviewed, however, it is mandatory that you complete the attached consent form. It is important to know that you can choose at any time during the research to discontinue your participation and all names will be changed in the research report in order to maintain confidentiality. Also, with your consent, interviews will be tape recorded. The tape recording and transcript of the interview will be destroyed following completion of the final report. Thank you for your time and cooperation.

Sincerely,

Erin R. Blew

I, _____, grant permission to be interviewed as part of this research project. I also understand that I can choose at any time during the research to discontinue my participation.

_____ _____
Participant's signature Date

I, _____, grant permission for the interview to be tape recorded. I understand that all tape recordings and transcripts will be destroyed after the final report has been completed.

_____ _____
Participant's signature Date

Forced Prenatal Intervention: Life, Autonomy, and Ethics

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Abstract

In this essay I argue a theoretical justification for a policy of forced medical intervention on pregnant women who refuse routine and life-saving treatment for a late-term fetus. I survey the case law and ethical principles that lead to our current conflict between life and autonomy, and then argue a three-point analysis that leads me to my conclusion that such intervention is justified. I argue that a late-term fetus has a significant moral worth which gives the fetus's life value in moral decision making. Next, I argue that the principles of utility impose an obligation upon the mother, and, lastly, that the state, in its role as *parens patriae* for minor children, has a duty to intervene to save near-term fetuses endangered by the refusal of a mother to submit to treatment. I then proceed to answer objections to my argument, stemming from autonomy and nondiscrimination toward women who will bear the burden of the proposal. I also investigate the "slippery slope" arguments against my proposal. I close with the caveat that pragmatic difficulties in enforcing court orders make my proposed policy unworkable in practice.

Introduction

On June 16, 1987, George Washington University Hospital petitioned the emergency hearing judge for the Superior Court of Washington, D.C., for an order asking permission to perform an emergency cesarean section on its patient, Angela Carter. Carter was a woman diagnosed with leukemia, but it had been in remission and during that time she married and became pregnant. During a routine medical check-up, physicians discovered that she had a tumor in her lung, and she was admitted to the hospital. Her prognosis was terminal.

Doctors informed Carter that the chances of saving her child were better if they prolonged her life for two weeks, so that the child could be delivered in the twenty-eighth week. Carter was equivocal about delivering the child, but consented to intubation to prolong her life. But under heavy sedation, she was unable to give consent to a caesarian section. The trial court convened in the hospital, and later, by her bedside, entered an order permitting the hospital to intervene. A stay was denied by a three-person motions panel in the District of Columbia Court of Appeals. The surgery was performed, but both mother and child died shortly after.[1]

The Angela Carter [A.C.] case shows the predicament facing courts, doctors, and hospitals when faced with a woman with a viable fetus, who is unable, or explicitly refuses to consent, to medical intervention to save a near-term fetus. OB/GYN's and neonatologists, who understandably view their jobs as to save the lives of near-term fetuses, are made uneasy by the prospect of simply watching a child die who could have been saved by routine surgery, while ethicists, legal commentators, and patients are concerned about courts subjecting a pregnant woman to surgery against her will.

Courts are thrust into an awkward position in the middle of these emergent medical situations. Fact patterns are complex, both ethically and medically, and constantly evolving during the course of the proceedings, as the mother grows closer and closer to term. And the rapidity with which counsel is forced to brief, and judges to decide these issues in, is diametrically opposed to the often glacial rate at which the courts operate. As a result, short orders dispose of the underlying matter, while actual reasoned decisions, if they are published at all, are forthcoming only after the matter is moot.

For example, the decision of the Supreme Court of New Jersey in *Raleigh Fitkin Memorial Hospital v. Anderson*[2] occupies only three pages in the reporter. The *per curium* opinion in *Jefferson v. Griffin Spalding*[3] consists of only the procedural history, the order of the trial court, and a one-line denial of a stay.

Courts are acutely aware of the uncomfortable position that they occupy in these decisions. As the Appellate Court[4] noted, "Our decision today is the result of considerable deliberation and that we have enjoyed two luxuries unavailable to the trial court: ample time to decide the case, and extensive briefs and oral argument from the parties." Even as it reversed, it commended the superior court judge for his conscientious handling of the case in difficult circumstances. The justices observed "that it would be far better if judges were not called to patients' bedsides and required to make quick decisions on issues of life and death."[5] Thus, clear moral guidance and standards will serve courts as well as patients and hospital staff, who are often forced to make rushed decisions in matters of life or death.

The first case of a fetus being treated as something akin to a legal person can be traced back to the 1880's. Fetuses were permitted to inherit from a parent who had died before the later live birth of the fetus. The assumption was that parents would wish to provide for a child who was conceived, but not born, at the time of death.[6] Fetal rights were later expanded to provide recovery for the torts against a fetus, contingent on the fetus' later live birth. It allows for the child to be compensated for injuries suffered, even if they occurred before birth, and, to a lesser extent, serves as a deterrent for tortuous actions on pregnant women.[7]

But it is important to note the distinction presented by these and our current cases. The fetus was not granted rights as a fetus, *qua* fetus, but rather as an acknowledgment that the fetus is what later became, at the point of live birth, a person who had a wrong inflicted against him or had claim to a parent's estate.

The question we now face is whether the state, in its role as *parens patriae* for minor children and as an expression of the social mores and beliefs of a community, can, while comporting with the rules of ethics, compel a mother to undergo unwanted treatment to save the life of a near-term fetus. I believe that such intervention can be morally justified, but that the unfortunate practicalities of enforcing court orders (which would be the means of effectuating such a standard) compel us not to institute such a policy. Instead of advocating the implementation of a policy, then, I argue that there is a theoretical justification for a position often viewed with disdain in the scholarly literature.[8]

To justify such a claim, I believe I must justify three separate, yet connected, premises that lead me to my conclusion. First, I must show that a near-term fetus has substantial moral status, and that status justifies employing a balancing test of harms to determine the justification of my proposition that forced medical intervention is warranted. Without a fetus having such significant and substantial moral status, the rights of the already living mother would clearly control, and such a balancing test would rightly be an unjustified intrusion on the rights of a fully autonomous and already living woman. I will suggest that a fetus, in these types of cases, is morally no different from an infant a few moments after birth.

Having shown that such a balancing test is warranted, I will then seek to employ that balancing test in these types of cases, employing the principles of utility. Utility, I believe, is the best standard to use, because in these cases, inevitably, one party or the other will be harmed, regardless of our decision. Therefore, I suggest that principles of utility permit us to weigh the harms inflicted on each party, and reach a moral judgment.

Lastly, I must show that the state has a significant interest that compels it to enforce the moral duty that I hope to establish in my second point. Just because a mother has a moral duty to consent to intervention does not mean that the state ought to enforce that moral obligation. But, I hope to show through the state's significant interest in protecting minors and associated duties, that it is therefore justified in compelling compliance with the moral duty above.

But before I begin my argument, it will be helpful to outline the major court decisions that provide the legal landscape for discussion of these cases, as well as the rights that are implicated by forced medical treatment cases. Forced treatment cases stand at interesting crossroads between abortion rights and the right of a competent patient to refuse treatment. They implicate rights to life and autonomy and are part of a legal and political battleground where, it seems, neither side is willing to compromise.

The first instance of the courts resolving the rights of a fetus (or, more precisely, the state's interest in the fetus) and the autonomy of pregnant women occurred in the leading case in abortion law: *Roe v. Wade*,[9] which was later modified in *Planned Parenthood v. Casey*.[10] In its decision in *Roe*, the Supreme Court recognized that there were two rights placed into conflict by anti-abortion laws: the right of the pregnant woman to have privacy and the non-interference from the state that is incumbent upon such a right, and "important and legitimate interest in protecting the potentiality of human life."[11] The Court struck a balance, establishing a system of what laws are permissible during each trimester of the pregnancy. As part of this, during the third trimester, after the point of viability, the state may regulate or ban abortion, except in cases where it is necessary for the health of the mother.[12]

In *Planned Parenthood v. Casey*, however, the Court clarified *Roe*. The *Planned Parenthood* court emphasized the state's interest in the potentiality of human life, claiming the portion of *Roe* which discussed that interest "has been given too little acknowledgment and implementation by the Court in its subsequent cases."[13] But it overturned the system of trimesters for how and when the state may regulate abortions. Instead, the question is now whether the regulation in question places an "undue burden" on the woman seeking an abortion.[14]

This conflict between the autonomy of the woman and the interest of the state in protecting potential life is relevant to the issue of forced caesarian sections, but an additional recognized right comes into play. A competent patient has the absolute right to refuse medical treatment, even if the treatment is lifesaving. A hospital, while, of course, interested in preserving life, cannot force treatment on a competent patient, simply because it believes the treatment is in the patient's best interests.[15] This right extends even to routine treatment, such as blood transfusions. Certain religious groups, such as Jehovah's Witnesses, object to even these routine procedures, and courts have upheld their right to refuse treatment.[16]

The right to refuse treatment respects the autonomy of individuals by allowing them to determine what, if any, course of treatment is best for them. This is as it should be—each person's individual assessment of risk versus rewards is different, and the medical profession, as well as the state, should honor that. In medical decisions, as in investments or life, each of us has a different threshold as to what outcomes are worth the risks—how much pain or suffering is acceptable for a chance at better or continued life.

But the more difficult question is whether the autonomy of an individual to make an informed medical decision to refuse treatment extends to a right to make an autonomous decision to refuse treatment which leads to the death of another. Even more to the point, is a near-birth fetus "another" that has interests or status that can be harmed?

This leads me to my first point of argument, which is that a late-term, imminently born fetus has significant moral status. More than that, I suggest that such a fetus has substantially the same rights as a newborn child. From this, I contend a balancing test between the rights of the mother and the status of the fetus should be employed to resolve conflicts between the two.

But a fetus is not a legal person.[17] If a fetus is not a person until live birth, where, then, can we draw support for the widely and deeply held intuition that a fetus has some sort of status, even if we disagree to its extent? We ought first to touch on the "potentiality" argument, because it is quite popular in legal and political circles, thanks to its adoption in both the *Roe* and *Casey* decisions. In essence, the potentiality argument posits that although a fetus is not a legal person, it holds the potential to become a legal person, and therefore should have the same rights as a person, or, to a lesser extent, be accorded significant moral status. While it seems intuitively correct, it is based on a logical fallacy, which is best pointed out by *reductio ad absurdum.*

As John Harris points out, just because I am potentially X does not mean that I should be treated as if I am X. We will all eventually die—but this does not mean we should treat each other as if we are already dead.[18] In addition, it is not just an embryo that holds the potential to become a human being. Both sperm and ova, separately, do as well, so long as certain biologically necessary conditions are met. Does this mean, then, that we must treat sperm and ova similarly to a fully developed person? If so, then women commit murder every month that goes by without a pregnancy, and the male population is guilty of attempted genocide with an increase in condom use. Arguments that only the fertilized egg has the true potential to become a human being are simply false. If the fertilized egg has the potential, and the ovum had the potential to become a fertilized egg, then, by transitivity, the ovum has the potential to become a human child.[19]

But there must be something else that drives the intuition that fetuses have some sort of moral standing. After all, physicians no doubt are aware of the biological facts outlined above, yet in a 1987 survey, forty-six percent of the heads of fellowship programs in maternal-fetal medicine thought that women who refused medical advice and thereby endangered the life of the fetus should be detained and forty-seven percent supported court orders for procedures such as intrauterine transfusions.[20] Even judges, who are not often driven to emotion in decisions, often recognize there is something more than a mass of cells to a developing fetus. One justice wrote, in describing his reasons for according a fetus some legal status,

> I have a new grandson. His name is Nicholas...We were able to view a sonogram and determine that Nicholas was a boy. We have pictures of sonograms taken when Nicholas was only fourteen weeks old. You can see his head, his eyes, his hands and feet. You could tell he was alive because he moved his arms and legs. He was so strong you could watch him move his mother's pregnant belly.[21]

Mary Anne Warren describes the moral status that we accord to things based on others considering them important as the principle of transitivity.[22] From this principle, we might agree on a moral obligation not to deface a place that religion X considers holy, even if we are of religion Y, based on the accord and moral status that religion X places on the location. Thus, the potentiality argument, though flawed on its actual philosophical merits, stands to grant some moral status to all fetuses, and especially late-term fetuses, simply because so many people look

at the fetus, and see not a mass of cells, but a growing person.

Warren also identifies other principles which, applied, would grant some moral status to the late-term fetus. Primary among these is the respect for life principle. With this, she states, "Living organisms are not to be killed or otherwise harmed without good reasons."[23] Whether one feels that a fetus is to be accorded great moral status or not, it is a biological fact that a fetus is a living thing. The question is, rather, whether respecting the mother's autonomous decision to refuse treatment is a "good reason" that justifies letting the living and late-term fetus die through refusal of medical intervention.

By Warren's interspecific principle, too, we tap into our intuition that humans are, because they are reciprocating moral agents, more morally valuable than other species that are also living and sentient.[24] There is, I think, the potentiality argument aside, an intuition that if given a "trolley car" choice between a late-term fetus and someone's pet, we would choose to hit the pet because while the fetus is yet to be born, we would not wish to terminate a developing human life.

Warren's human rights principle, then leads me to my argument that a late-term fetus is substantially similar in moral value to a newborn child. Warren writes, "Human beings who are capable of sentience but not of moral agency have the same rights as do moral agents."[25] She places an important limitation on this—namely, the principle of respect for autonomy, but I shall return to that later. By this principle, she notes that toddlers and newborns, who are not reciprocating moral agents because of their immaturity, are still accorded the same rights as you or I who are.

But from this, we must ask: Is there any relevant moral difference between a child who is viable and on the cusp of being born and one that has just emerged from the womb? If the answer is no, then we must view the imminent fetus as having substantially similar status, approaching that of a newborn, with a few important exceptions.

What, then, separates a newborn just out of the womb, and the fetus that is hours from birth? If removed from the womb, the latter is the equal of the former. The only thing separating the two is the space each occupies relative to the mother's body. The newborn, it may be said, is seen as an independent entity in society and capable, now, of social interaction. But the child just from the womb interacts little except to fuss or cry, and is just as wholly dependent on others (even if those others are not the mother). I see, then, very little relevant difference between the two and believe that all of this analysis and these principles lead to a fetus being accorded significant moral status which justifies a balancing test being employed between the moral status and accordant duties that others owe such a fetus and the rights of the mother.

What, then, is the appropriate balancing test? I believe that such a balancing test should be founded on the principles of utility. Short of a prognosis being incorrect (which does happen), there is no way that we may simultaneously respect both the rights of the mother and the duties owed to the fetus and not have harm come to either. Therefore, utility, a balancing of the harms, risks, and benefits on both sides, is most appropriate. Since everyone's rights cannot be respected by taking a deontological point of view, the most appropriate analysis is one based on achieving the greatest good while minimizing the inevitable harms.

In these cases that we discuss, the sacrifice is not the life of the mother, the sacrifice of which would be indefensible, but rather submission to surgery which runs counter to a deeply held and genuine belief, one that is often religious. Therefore, we need to weigh the life of the fetus against these deeply held beliefs and decide if, from it, a moral obligation is present, based on the benefits and harms caused to each by our possible courses of action.

Peter Singer in his famous essay, "Famine, Affluence, and Morality," posits a simple proposition when framing duties to others:

"if it is in our power to prevent something bad from happening, without thereby sacrificing anything of comparable moral importance, we ought, morally, to do it."[26] While Singer discusses our duty to provide funds for famine relief in Africa, the principle is relevant in all sorts of contexts. As utility makes no moral distinction between a failure to act and intentionally causing wrong, in this instance, the argument that the mother did not intend the death of the fetus, but instead, only desires that her wishes be respected, is rejected. Furthermore, to apply the doctrine of double effect, "the bad effect [here, the death of the fetus] is permissible only if a proportionate reason compensates for permitting the foreseen bad effect" or, more directly, "the good effect must outweigh the bad effect."[27]

No doubt the mother will experience some discomfort from undergoing caesarian section (the most commonly asked for intervention in these cases), and the risks are real but manageable. Without surgical intervention, however, the rate of mortality for fetuses, given a correct diagnosis, is all but certain.[28] Given this, I believe that principles of utility dictate that the balance of harms and benefits weighs heavily toward the duties owed to the fetus, and that letting the fetus die through inaction is a greater evil than the good of respecting the woman's autonomous judgment.

But what, then, about the criticism that although what the woman is being asked to give up is not of equal value, it is certainly significant, as it asks her to surrender deeply held beliefs and submit to invasive abdominal surgery? While Singer strenuously argues that his principle applies, regardless of whether the person one allegedly has a duty to is a stranger or an intimate—even if we reject this principle of nondiscrimination—there is no doubt that the mother is in a unique position to assist.

While noting the distastefulness that accompanies forced surgical intervention, commentator John Roberts argues that the unique relationship between fetus and mother imposes a duty to aid. As he notes, the mother no longer possesses, at the end of pregnancy, a severance right to the relationship—she must still undergo the birthing process, even if it is to expel a dead fetus, with the incumbent pain that it entails. As the birthing process must be undergone in some form or other, and because of the unique position that the mother is in to render aid, Roberts concludes, "[t]o impose on the mother a duty to undergo surgical delivery where it is necessary to save the child's life or to prevent it from being injured is not unreasonable when she has chosen to lend her body to bring the child into the world."[29] In essence, it is unreasonable and immoral for a mother who has chosen to bring a child this far into pregnancy to "back out" now. As the child must be "born" in some form, there is a duty on the mother to submit to procedures that provide the best chance that the birth is a live one, because no other person than her can render that aid.

But my analysis above only works so long as we agree that utility is the correct principle to use. There are strong objections to such a view. For example, in *McFall v. Shimp*,[30] a court affirmed the principle that "one human being is under no legal compulsion to give aid or to take action to save another human being." This suggests an absolute bar to any claims based on utility. What permits me to reject rights in the name of utility? Indeed, McFall was the only closely matched donor for his cousin, so if we cannot compel him to submit to unwanted medical treatment, why a mother who also is the only person who may render aid? The *McFall* decision seems to reflect Kant's categorical imperative that we may not use people merely as means to an end unless they also participate in those ends.

But implicit in the court's decision is that McFall had no duty to render aid under any circumstances in any way. If Shimp were starving and his cousin McFall were a millionaire, Shimp could not sue McFall to compel him to give Shimp five dollars for lunch. While it may be morally reprehensible, it is legally permitted.

The same is clearly not true of mothers and children, and I maintain that there is little relevant moral difference between the legal person that is a newborn and the legal nonperson that is a near-term fetus. Statutes in all states hold parents responsible for the well-being of their children and impose a duty to provide what is necessary for their upkeep, including food, shelter, and medical care.[31] These same statutes provide for the removal of children or state intervention when these needs are not met. Thus, the question becomes less whether any duty to the near-term fetus exists, than whether that duty extends to the violation of bodily integrity of the mother.

Judith Thomson suggests that we have no duty to provide use of our body to another, even if that means the death of the "other." Talking of a talented violinist who appears mysteriously, and is dependent on one for survival, she claims that severing the connection that holds the two together is not unethical, because the violinist was never desired, despite his reliance on the woman for survival.[32] But Thomson is specifically talking about a severance right, separate from a right to "secure the death of the unborn child." As I discuss above, as the woman must still undergo the birthing process, this is no longer a severance right, which is the right Thomson advances. The women in our cases do not wish to be separated from the child, but rather knowingly take the risk inherent in refusing medical treatment despite wishing for the child.

In addition, the mother derives real benefits from the intervention, and thus participates in the ends. As Frank Chervenak and Laurence McCullough point out, a pregnant mother derives the benefit to herself of decreased mortality.[33] Thus, although she does not wish to, she also participates in the ends, defeating a deontological objection of her being a "means merely." Even if this response is not quite satisfying, we may appeal to the harms principle and argue that an autonomy right to one's body ceases when exercising that right leads to the death of an innocent person through inaction, which may have otherwise been prevented through routine and minimal-risk surgical intervention.[34]

Thus, applying principles of utility, we discover that there is a moral obligation upon a mother to consent to reasonable risks to save the life of her near-term fetus, despite personal objections. Objections to such a duty stemming from deontological principles are overcome by the benefits to the mother as well as applications of the harms principle.

But even if we agree that, from principles of utility, the mother has a duty to undergo such procedures, regardless of personal beliefs; it is another step to have the state enforce that duty. We may agree I have a duty to be faithful to my girlfriend, but we would also agree that the state shouldn't haul me off to jail for cheating on her. Thus, I must prove that the state's interest in the life of the late-term fetus is so compelling as to justify its exercise of coercive force to protect that interest.

The state, no doubt, has an interest in protecting minor children. The Division of Youth and Family Services (or organizations like it in other states) exists for that very purpose, and the state, in its role as *parens patriae,* legitimately exercises authority to remove children from abusive households and separate unfit mothers from children, despite a compelling right that a parent has from autonomy to raise a child according to the manner in which the parent sees fit. While the state should, and morally must, respect differences in religious beliefs and philosophies of parenting, the controlling consideration in cases of the well-being of a child must always be, as the mantra in the family court goes, "the best interests of the child."

I think it can be generally agreed that life is in that child's best interests. Although the parents of a child may hold a belief that the child's death is preferable to certain other actions (such as certain medical procedures), the problem is that the minor child is incompetent to express his own views. The

parents may be Jehovah's Witnesses who can validly refuse a blood transfusion for themselves, because they are fully competent, but if the child should differ from those beliefs (and there is no way to determine if he does, as he is too young), an objective standard is required. That standard should be the "best interest" test.

In *State v. Perricone*[35] the New Jersey Supreme Court affirmed an order allowing a blood transfusion to a minor child over the objections of the parents, Jehovah's Witnesses, who refused to grant consent. The Court reasoned that, the good intentions of the parents notwithstanding, their actions constituted neglect.[36] While the couple could not be criminally punished, the state was within its right to exercise its power as ultimate guardian of minor children to order treatment.

Of course there are significant differences between ordering treatment on a child outside the womb, and one that is inside, because the latter must necessarily subject the mother to unwanted surgery rather than compelling consent for another to undergo surgery. But the risk from that surgery is manageable. In both *Perricone* and in other cases, such as *Raleigh-Fitkin Memorial Hospital v. Anderson,* the same interest was being overridden—the right to have medical treatment in accordance with religious beliefs, irrespective of the invasiveness of the treatment.

Having met all three criteria that I outlined earlier, I will now address objections to my arguments. As I rely heavily on Mary Anne Warren's multifaceted criteria, it would be disingenuous to say that the conclusions I draw are necessarily supported by her applications of those criteria. Namely, she places the principle of agent's rights (autonomy, essentially) above that of human rights, that accords rights to individuals such as children who are not fully moral agents.[37] But to make such a principle of human rights apply only "within the limits of [the agent's rights principle]," it seems that the liberty of one individual can restrict the moral rights of nonagentive but sentient human beings, in essence, children or fetuses. Perhaps this makes sense in the context that a moral agent (a parent) must restrict the rights of the not fully formed agent (the child) to rear him, but it also permits, it seems, infanticide, as Warren herself concedes.

Warren at least deserves credit for facing this, stating that "when... it is impossible successfully to rear all infants that are born... a tolerant attitude toward early infanticide is kinder and more just than the persecution of parents."[38] But even limiting such tolerance to extraordinary circumstances is abhorrent. When there are fit parents who yearn for the opportunity to adopt, and programs in place to ensure placement for every unwanted child and then some, infanticide is unjust and unfathomable, as well as insulting to the vast majority of parents who would willingly give their own existence and life to provide for their children. Thus, Warren's fourth principle of human rights should stand equivalent with her third of agent's rights in claims relating to life. While a child may not hold similar rights to adults with regards to property, voting, and so on, it is difficult to suggest that the religious beliefs of a parent should take precedence over the life of that parent's child.

Some commentators suggest that a rule such as that I suggest is discriminatory against females, and relegates them to a lower class based on their ability to rear children. Dawn Johnsen analogizes that the ability to bear children is to sex discrimination what dark skin is to race discrimination—immutable, and used as a justification to oppress another class.[39] Perhaps the best response is simply to admit her premise that, indeed, women will be exclusively harmed by such requirements. But the requirements of justice and nondiscrimination are simply that we treat equally those who are similarly situated. If men had the ability to bear children, they would, without hesitation, be included in my analysis above. But it is a biological fact that they cannot. That there is only one group of people who can render aid does not lessen their obligation to render that aid.

Amy Kay Boatright also argues that such policies enforce an ideal of Western medical practice upon women who hold differing religious or cultural values. A bright line test that rejects any notion of trying to balance fetal and maternal rights, she says, respects diversity and means that, "[a] pregnant mother will not be made to choose between carrying her fetus to term and maintaining control of her body and her life."[40]

But such a principle engages in a nasty bit of cultural relativism, that we are not permitted to judge certain mothers unfit simply because they hold different cultural or moral values. There is much to be said for diversity and the many different ways of life that we may all practice, within the bounds of permissible ethical behavior. But "diversity" must cease and the state must step in where there is objective evidence that a course of action is detrimental to the well-being of a child, or, in this case, an about-to-be-born child. Cultural differences aside, refusing to consent to certain medical procedures, such as caesarian section, can and will lead to the deaths of children who would have lived otherwise. The U.S. Supreme Court held in *Reynolds v. United States,* "laws are made for government actions, and while they cannot interfere with mere religious beliefs and opinions, they may with practices"[41] when those practices harm the well-being of another. That is the case here. The actions of the mother harm the well-being of the child, and, so, while perhaps criminal prosecution is unwise, and, in New Jersey, at least, forbidden, civil orders compelling proper treatment are justified.

Lastly, as such a policy of forced medical intervention will be seen as a gradual wearing away of abortion rights, we should address the issue of the slippery slope. In his trenchant analysis of the slippery slope, Eugene Volokh discusses what he calls "attitude altering slippery slopes."[42] As a result of the "normative power of the actual," he argues that people accept as legal (or moral) something simply because it is that way now. An individual has neither time nor inclination to become an expert on all sorts of matters, be they economic, medical, or moral. Instead, they delegate this to other individuals whom they trust, such as policy-makers and doctors.[43] A person may say, "I don't know much about ecstasy, but I bet that Congress did a lot of research and talked to a lot of experts, so I am sure that banning it was a good idea."

Applied here, the ACLU argued in one case that appointing a guardian to represent the interests of a fetus in a case "would have allowed the state to micromanage the pregnancies of women throughout Florida, determining what vitamins they take, what prenatal testing they obtain, and the method by which they deliver" as well as "undermine the fundamental right to choose abortion."[44]

It's hard to soothe fears of a slippery slope, and perhaps some advocates of forced caesarian sections do wish for an end to abortion. But I believe my proposition can be distinguished from concerns about abortion rights because the women involved in these cases do truly desire the child. There is no doubt that if they could have a healthy baby vaginally or without medical intervention, they would do so. This is not an issue about abortive choice, for they do not wish to abort. Instead, this is a question of the justified limits for refusing intervention. After all, abortion is surgical, as is caesarian section. I believe I may safely presume that these conscientious objectors to caesarians would submit to a c-section before a surgical abortion, or at least find both equally distasteful. While the concern, I understand, is also in general about the state's involvement in women's prenatal decisions, that right cannot be absolute, the same way that parental decisions post-birth are respected, but not inviolate. When a child on the cusp of being born is at risk, the state has a duty to act, the same way it would for a newborn.

I end with a caveat. While such intervention is justified, its practical enforcement is impossible, and thus inadvisable. Courts

cannot force compliance with orders by imprisonment and fine, as it might do in traditional contempt proceedings. Instead, it is only by forcible restraint that compliance can be ensured. As the Court in *A.C.* warned,

> Enforcement could be accomplished only through physical force or its equivalent. A.C. would have to be fastened with restraints to the operating table, or perhaps rendered unconscious by forcibly injecting her with an anesthetic, and then subjected to unwanted major surgery. Such actions would surely give one pause in a civilized society, especially when A.C. had done no wrong.[45]

As the Illinois Supreme Court reasonably suggested in refusing to order a woman to submit to a caesarian section, noting that even the state did not advocate forcible detainment and sedation, "this court, as a simple matter of policy, will not enter an order that is not intended to be enforced."[46] Indeed, effectuation is difficult even if it is sought. In *Fitkin,* the appellee left the hospital against medical advice, rendering enforcement of the order difficult. In *Jefferson,* the appellant went into hiding to avoid enforcement but delivered a healthy baby vaginally. While the issues surrounding enforcement of judicial orders and the wisdom of judicially ordering the unenforceable could occupy a whole other paper, the thought of forcibly sedating and cutting open a woman who has done no wrong should give pause to even defenders of fetal rights. While perhaps a policy of court-ordered intervention may be tenable if it occurred in a world where judicial orders were unquestionably followed, such a utopia is not, it appears, possible.

Forced medical intervention raises difficult issues regarding both maternal and fetal rights. While the moral status of the about-to-be-born justifies a policy of the state to force maternal cooperation with efforts to save the child in ethical theory, it appears that the practical difficulties of enforcement make such a policy unwise and inadvisable for courts and policymakers.

NOTES

1 The fact pattern is drawn from the D.C. Court of Appeal's motion panel and later en banc decisions, reported respectively as *In re: A.C.*, 533 A.2d 611 (1987) and *In re: A.C.*, 573 A.2d 1235 (1990).
2 42 N.J. 421 (1964).
3 247 G.A. 86 (1981).
4 *In re: A.C., supra* 573 A.2d at n2.
5 *Id.*
6 Dawn Johnsen, "The Creation of Fetal Rights: Conflicts with Women's Constitutional Rights to Liberty, Privacy, and Equal Protection." 95 *Yale L.J.* 599 (1986) at 601.
7 *Id* at 601-602.
8 *See, e.g.*, Johesen, *supra*, and Kolder, *ante*, as well as Boatright, *ante.*
9 410 U.S. 113 (1973).
10 505 U.S. 833 (1992).
11 *Roe, supra,* 410 U.S. at 163.
12 *Id* at 732-733.
13 *Planned Parenthood, supra,* 505 U.S. at 871.
14 *Id* at 712-713.
15 *See Cruzan v. Director, Missouri Department of Health,* 497 U.S. 261 (1990).
16 *See, e.g. Baumgartner v. First Church of Christ, Scientist,* 141 Ill. App. 3d 898 (1986).
17 *Roe, supra,* 410 U.S. at 161.
18 John Harris. *The Value of Life.* London: Routledge & Kegan Paul, 1985, at 11.
19 *Id* at 12.
20 Kolder, V. E., et al. "Court-ordered obstetrical interventions." 316 *New England Journal of Medicine* (1987) at 1192.
21 *In re: Guardianship of J.D.S.*, 29 Fla. L. Weekly D 198 (2004) at 43 (Pleus, J., dissenting).
22 Mary Anne Warren. *Moral Status.* Oxford: Clarendon Press, 1997 at 170-171.
23 *Id* at 149.
24 *Id* at 168.
25 *Id* at 164.
26 Peter Singer. "Famine, Affluence, and Morality." 1 *Philosophy & Public Affairs* (1972).
27 Tom Beauchamp and James Childress. *Principles of Biomedical Ethics.* 5th ed. New York: Oxford University Press, 2001, at 129.
28 Frank Chervenak and Laurence McCullough. "Justified Limits on Refusing Intervention." *Healthcare Ethics in a Diverse Society.* Eds. Michael Brannigan and Judith Boss. Mountain View: Mayfield Publishing, 2001, at 239-240.
29 John Roberston. "Procreative Liberty and the Control of Conception, Pregnancy, and Childbirth." 69 Va. L. Rev. 405 (1983) at 456.
30 10 Pa. D. & C.3d 90 (1978).
31 *See, e.g.* Indiana Code Annotated 31-34-1 Sec. 9 (Defining "a child in need of services" as one who "is depived of nutrition that is necessary to sustain life; or... is deprived of medical or surgical intervention

that is necessary to remedy... a life-threatening medical condition").

[32] Judith Thomson. "A Defense of Abortion." *Healthcare Ethics in a Diverse Society.* Eds. Michael Brannigan and Judith Boss. Mountain View: Mayfield Publishing, 2001, at 95-107.

[33] Chervenak and McCullough, *supra*, at 240.

[34] *Id.*

[35] 37 N.J. 463 (1962).

[36] *Id* at 477.

[37] Warren, *supra*, at 156 and 164.

[38] *Id* at 165.

[39] Johnsen, *supra*, 95 Yale L.J at 620.

[40] Amy Kay Boatright. "State Control Over the Bodies of Pregnant Women." 11 J. Contemp. Legal Issues 903 (2001) at 934.

[41] 98 U.S. 145 (1878) at 148.

[42] Volokh, Eugene. "The Mechanisms of the Slippery Slope." 116 *Harvard Law Review* 1026 (2003) at 1077.

[43] *Id* at 1078.

[44] American Civil Liberties Union. "Florida Court Refuses to Appoint Guardian for a Fetus." ACLU.org. Jan 9, 2004. American Civil Liberties Union. 20 March 2004 <http://www.aclu.org/ReproductiveRights/>.

[45] *In re: A.C. supra* at n8

[46] *In re: Baby Boy Doe, supra* at 335.

A Comparison of Evaporative Water Loss Within and Between Two Populations of the Timber Rattlesnake (*Crotalus horridus*)

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Abstract

Rates of evaporative water loss and percent lipid content were determined using shed epidermis of neonatal and adult timber rattlesnakes (*Crotalus horridus*) from the Coastal Plain Pine Barrens of New Jersey and from the Appalachian Mountains of northern Pennsylvania. Differences between populations resulting from habitat and within populations from age were tested. One particular goal was to evaluate the assumption that neonatal aggregations are a behavioral response to greater water loss prior to the first ecdysis. Rates of evaporative water loss were not found to differ according to locality ($P > 0.05$), but rates were significantly different for age. The rate of evaporative water loss for adult *C. horridus* was greater than that for neonates ($P < 0.0025$). Mean percent lipid content, extracted using 2:1 chloroform:methanol, did not differ by locality ($P > 0.05$), but differed between age, paralleling the results found for evaporative water loss rates. The percentages of lipids extracted from *C. horridus* neonate sheds were greater than those extracted from adults ($P < 0.0005$). The results suggest that habitat differences have not resulted in a measurable alteration in cutaneous water loss rates of *C. horridus*. However, in both populations, the epidermis of adults has a greater permeability than the epidermis of neonates. This particular finding is counter to that typically suggested in the existing literature. A comparison of mean total body cutaneous water loss per gram of tissue showed that neonates do, however, lose potentially 2.4 times greater the amount of water than adults, relative to volume. This supports the notion that neonatal aggregations may function to reduce exposed surface area and limit evaporative water loss.

Introduction

Research beginning in the 1960s refuted the assumption that the reptilian integument is essentially impermeable to water (Bentley and Schmidt-Nielsen, 1966). Of the sources of evaporative water loss, cutaneous water loss seems to be the most significant for snakes (e.g., Prange and Schmidt-Nielsen, 1969; Dmi'el, 1972; Cohen, 1975). Lipids, located primarily in the mesos layer of the epidermis, have been shown to function as the main barrier to evaporative water loss (Roberts and Lillywhite, 1980, 1983). Evaporative water loss rates and skin permeability are affected by factors such as habitat aridity, exposed surface area, temperature, position of the animal in the shedding cycle, activity, and hydration state of the epidermis (reviewed in Lillywhite and Maderson, 1982; Mautz, 1982). Although interspecific comparisons abound, it appears that little attention has been given to intraspecific differences in water loss, especially the effects of habitat variation and age on water loss of conspecific snakes.

One goal of this study was to compare evaporative water loss rates and percent lipid content between populations of timber rattlesnakes (*Crotalus horridus*) from two

different habitats. In Pennsylvania, *C. horridus* occupies mountainous habitat that is composed of "second-growth deciduous hardwood forest" interspersed with open rocky areas (Reinert, 1984a,b). Overwintering hibernacula are rocky dens with a southern opening, which appears to be typical of the species, especially in the Northeast (Martin, 1992; Brown, 1993). In the lower elevation Coastal Plain Pine Barrens of southern New Jersey, hibernation occurs underground in wetland habitats where the snakes are immersed in water (Burger, 1934; Kauffeld, 1957; Reinert and Zappalorti 1988a,b).

Another goal of this study was to compare evaporative water loss and epidermal lipid content of neonatal and adult *C. horridus*. All rattlesnakes bear live young (Klauber, 1972). Prior to the first ecdysis, neonates possess the skin they had while inside their mother, which is presumed to be more permeable than adult skin to allow passage of nutrients from the amniotic fluid (Graves et al., 1986). It has been suggested that the first ecdysis helps neonates to function in their new terrestrial environment through the sloughing of this presumably more permeable "protointegument" (Graves et al., 1986; Tu et al., 2002). Neonatal *C. viridis* demonstrated greater evaporative water loss, lower lipid content, and aggregative behavior prior to the first ecdysis (Graves et al., 1986). Furthermore, Tu et al. (2002) indicate that the lipids of the mesos layer double after the first ecdysis in snakes, and thus predict higher rates of evaporative water loss in neonates. However, recent research by Ball (2004) presents contradictory evidence that the shed epidermis of neonatal corn snakes (*Elaphe gutatta gutatta*) contains a greater percentage of extractable lipids than that of adults.

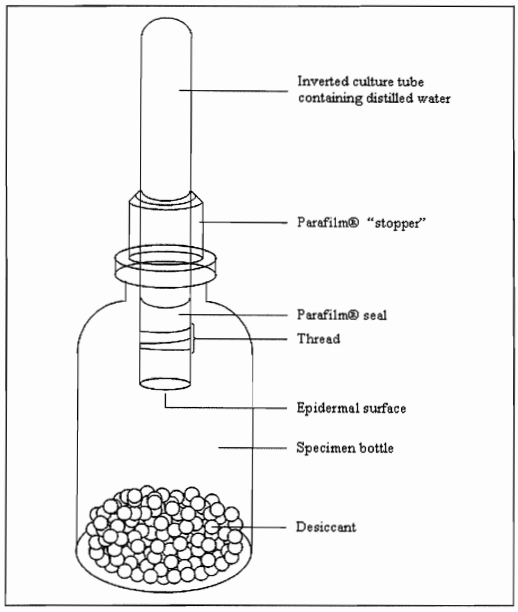
Materials and Methods

Evaporative Water Loss

An *in vitro* preparation of shed outer epidermis was used to compare the rates of evaporative water loss from four experimental groups of *Crotalus horridus* defined by age and location. Shed skins were obtained from five neonatal and five adult *C. horridus* from the Coastal Plain Pine Barrens of southern New Jersey (Burlington Co. and Ocean Co.) and five neonatal and five adult *C. horridus* from the Appalachian Mountains of northern Pennsylvania (Clinton Co., Lycoming Co., and Tioga Co.). Four samples were taken from the dorsal epidermis of each shed skin and soaked briefly in distilled water for ease of manipulation. The skin samples were gently stretched over 10 x 75 mm culture tubes (tube opening = 0.58 cm^2) containing 2.0 ml of distilled water with the inner surface of the epidermis facing the inside of the tube. Samples were held in place with thread, trimmed to remove excess skin around the neck of the tube, and then sealed with Parafilm® (American National Can, Greenwich, CT), ensuring that the skin surface over the tube opening remained unobstructed. No skin other than the surface over the tube opening was permitted to be exposed. The outer epidermal surfaces were examined for tears using a stereomicroscope, and damaged samples were discarded. The completed tubes were placed in an upright position overnight to allow the skin samples to achieve similar states of hydration. The tubes were then inverted allowing the water to contact the inner surface of the skin sample to simulate *in vivo* conditions (Burken et al., 1985). Each inverted tube was suspended in the mouth of a 30 ml serum bottle containing 3.50 g of t.h.e.® desiccant (EMD Chemicals Inc., Gibbstown, NJ) to remove moisture and maintain comparable humidity levels for each sample. Parafilm® was wrapped around the outer surface of each test tube to create a "stopper" to seal the system while allowing the test tubes to be removed for periodic measurements. Figure 1 is a diagrammatic representation of the *in vitro* preparation used to measure water loss rates. Masses of the sample tubes (to the nearest 0.001 g) were taken at 12 h intervals. A total of 10 mass measurements were taken per sample. Leaking samples, noted by accumulation of water on the outer skin surface and/or dramatic weight

loss, were discarded. Discarded samples were replaced to maintain 3-4 skin samples per snake. The desiccant was replaced as necessary. Ambient laboratory temperature recorded at the time of each massing ranged from 21.5-24.0° C. All Pine Barrens samples were tested together, followed by all Appalachian Mountain samples.

Figure 1. Diagram of *in vitro* preparation of shed dorsal epidermis used to determine evaporative water loss rates of neonatal and adult *Crotalus horridus* (see Materials and Methods).



For each sample, cumulative change in mass (in mg) was determined. This cumulative change in mass equates to the net amount of water loss. Using the evaporative surface area (0.58 cm^2), the mass of water loss per surface area (mg/cm^2) was calculated for the 10 observations for each sample. Cumulative mass of water loss per surface area was plotted against time (in h). The slope of the line, equal to the rate of evaporative water loss (in mg/cm^2h), was determined by a Model I linear regression (Sokal and Rohlf, 1995). From these values a mean rate of evaporative water loss was calculated for each snake. This mean value was used to represent each snake skin sample in statistical analyses to avoid problems associated with non-independence and pseudoreplication (Sokal and Rohlf, 1995). The mean evaporative water loss rate for each experimental group (Pine Barrens neonates, Pine Barrens adults, Appalachian Mountain neonates, and Appalachian Mountain adults) was then determined using the means from each of the five snakes.

Lipid Extraction

Lipid extraction was also performed on shed dorsal epidermis of five neonatal and five adult *C. horridus* from the two localities. The procedure used followed that of Stokes and Dunson (1982). Because of size constraints, three samples per adult and two samples per neonate were used. Different mass samples were used for Pine Barrens adults and neonates, but similar mass samples were used for Appalachian Mountain adults and neonates to determine if sample mass had an impact on the percentage of lipids extracted. Samples were first dried over 18.0 g t.h.e.® desiccant in sealed 250 ml beakers. After 24 h, initial masses were taken (to the nearest 0.001 g). Samples were soaked for 24 h in a 2:1 chloroform:methanol (by volume) extraction mixture in sealed 175 cc specimen bottles. After another 24 h, the samples were removed from the mixture and sequentially washed once with ~10 ml of fresh 2:1 chloroform:methanol and twice with ~10 ml of distilled water. Samples were blotted with paper toweling, allowed to air dry for a brief period to remove excess moisture, and then returned to their respective desiccant beakers. After 24 h, the samples were removed and the final dry masses were recorded. Fresh desiccant was supplied as needed. Ambient laboratory temperature recorded at the time of each massing ranged from 20.9-23.0° C. Again, all Pine Barrens samples were tested together, followed by all Appalachian Mountain samples.

Percent lipid content was determined using the following equation (Roberts and Lillywhite, 1983):

$$\frac{D-E}{D} \times 100 = \%\ \text{lipid content}$$

where D is the initial dry mass of the shed skin prior to lipid extraction, and E is the dry

mass following extraction. From the individual sample lipid percentages, mean percent lipid content was determined for each snake. As with water loss rates, this mean value was used in statistical analyses to avoid problems associated with non-independence and pseudoreplication (Sokal and Rohlf, 1995). The mean percent lipid content for each experimental group was then calculated from the means for each of the five snakes.

Statistical Analysis

A two-way, nested analysis of variance (Zar, 1999) was used to compare rates of evaporative water loss by location (Pine Barrens and Appalachian Mountains) and age (neonate and adult). Location and age were factors that were explicitly chosen, while the snake samples used were considered to be random. Thus, snakes within groups were treated as a random, nested factor. This statistical test was performed on both raw water loss values and log transformed values (Sokal and Rohlf, 1995).

The same statistical analysis was used to compare the percentages of extracted lipid content by location and age. This analysis was carried out on both raw lipid percentages and arcsine transformed lipid proportions (Sokal and Rohlf, 1995).

Prior to ANOVA comparisons, a modified version of Levene's Test (Conover et al., 1981; Kirby, 1993) using deviations around group medians was performed on both water loss and lipid data to assess the homogeneity of group variances. All statistical analyses were performed using SYSTAT 10 (SPSS Inc., Chicago, IL).

Determination of Total Body Surface Area and Total Body Cutaneous Water Loss

Total body surface area was estimated from previously collected field data (HKR, unpublished data). Masses for neonates and adults (length > 90 cm) from the Pine Barrens and Appalachian Mountain populations of *C. horridus* were converted to surface area values using the following equation from Mautz (1982):

$$A = 12.5\,W^{0.67}$$

where A is surface area (in cm^2) and W is body mass (in g). Ten snakes per group were selected at random from sites within each locality. Surface area-to-volume ratios were calculated by dividing surface area by body mass, assuming 1 g tissue = 1 ml water.

Total body cutaneous water loss was found by multiplying a given snake's surface area by the mean rate of evaporative water loss calculated for its respective group from the preceding experiments. To find water loss relative to snake volume, total body cutaneous water loss was divided by body mass. Mean surface area:volume and total body cutaneous water loss:volume were then calculated for each age group.

RESULTS

Adult *C. horridus* demonstrated higher cutaneous evaporative water loss rates and lower skin lipid content than neonatal *C. horridus* in both the Pine Barrens and Appalachian Mountain samples. The mean rates of evaporative water loss and mean percent lipid content of shed skin samples of neonatal and adult *C. horridus* from the Pine Barrens and Appalachian Mountains are given in Table 1.

Table 1. Rates of evaporative water loss determined in vitro and percent lipid content extracted with 2:1 chloroform:methanol (by volume) from shed dorsal epidermis of neonatal and adult *Crotalus horridus* from the New Jersey Pine Barrens and the Appalachian Mountains of northern Pennsylvania.

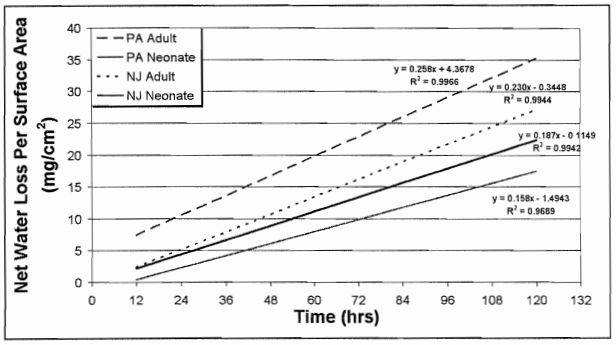
Location and Age	Evaporative Water Loss (mg/cm^2h)* $\bar{Y} \pm$ SE (N)	% Lipid Content† $\bar{Y} \pm$ SE (N)
Pine Barrens		
Neonates	0.190 ± 0.024 (5)	16.23 ± 1.81 (5)
Adults	0.227 ± 0.030 (5)	7.79 ± 0.85 (5)
Appalachian Mountains		
Neonates	0.156 ± 0.012 (5)	15.97 ± 1.03 (5)
Adults	0.261 ± 0.026 (5)	8.44 ± 0.32 (5)

*Significant difference between neonates and adults ($F_{s(1,16)} = 13.75$, $P < 0.0025$).
†Significant difference between neonates and adults ($F_{s(1,16)} = 52.69$, $P < 0.0005$).

A two-way, nested ANOVA indicated that mean water loss rates were significantly different between neonates and adults (Age: $F_{s(1,16)} = 13.75$, $P < 0.0025$) but not between Pine Barrens and Appalachian Mountain samples (Location: $F_{s(1,16)} = 0.18$, $P > 0.05$).
No significant interaction was found between location and age (Location x Age: $F_{s(1,16)} = 2.71$,

$P > 0.05$). The results presented are based upon untransformed data, because both transformed and untransformed data provided the similar significance levels, and Levene's test indicated homogeneity of group variances for the untransformed data ($F_{s(3,56)} = 1.05, P = 0.38$). Figure 2 illustrates the similarities in the rates of evaporative water loss between localities and the differences in the rates between neonates and adults for representative samples of data collected from each group.

Figure 2. Rates of evaporative water loss obtained in vitro for representative neonatal and adult Crotalus horridus using shed dorsal epidermis samples from snakes of the New Jersey Pine Barrens and the northern Pennsylvania Appalachian Mountains. Rates are significantly different between neonates and adults but not for location (see Table 1).



Likewise, a two-way, nested ANOVA indicated that the percent lipid content differed significantly between neonate and adult *C. horridus* (Age: $F_{s(1,16)} = 52.69, P < 0.0005$), but not between the Pine Barrens and Appalachian Mountain samples (Location: $F_{s(1,16)} = 0.03, P > 0.05$). No significant interaction was found between location and age for lipid content (Location x Age: $F_{s(1,16)} = 0.001$, $P > 0.05$). As with evaporative water loss rates, the results presented for lipid analysis are also based upon untransformed data, because both transformed and untransformed data provided similar significance levels, and Levene's test indicated homogeneity of group variances for the untransformed data ($F_{s(3,36)} = 0.58, P = 0.63$).

Mean surface area per volume (cm^2/ml) and total body cutaneous water loss per volume (mg/mlh) are reported in Table 2. Since no difference in evaporative water loss or percent lipid content was found between localities, data are presented on the basis of age only. Neonates have a higher surface area-to-volume ratio than adults and potentially lose 2.4 times greater the amount of water than adults from their total body surface area, relative to volume.

Table 2. Mean surface area-to-volume ratio and mean total body cutaneous water loss per volume for neonatal and adult *Crotalus horridus*. Surface area-to-volume is calculated from mass data, using the surface area equation $A = 12.5W^{0.67}$ (Mautz, 1982), and assuming 1 g tissue = 1 ml water. Total body cutaneous water loss per volume is found using values for evaporative water loss in Table 1.

Age	Surface Area-to-Volume Ratio (cm^2/ml) Y ± SE (N)	Total Body Cutaneous Water Loss Per Volume (mg/mlh) Y ± SE (N)
Neonates	4.49 ± 0.08 (20)	0.774 ± 0.017 (20)
Adults	1.32 ± 0.03 (20)	0.322 ± 0.010 (20)

DISCUSSION

Studies on various snake species suggest that differences in evaporative water loss rates and skin permeability are related to the type of habitat occupied (e.g., Gans et al., 1968; Cohen, 1975; Roberts and Lillywhite, 1983; Burken et al., 1985). The general habitat occupied by *C. horridus* in the Pine Barrens and Appalachian Mountains exhibits obvious differences with respect to forest floor and canopy structure (Reinert, 1993). The Coastal Plain Pine Barrens have low topographic relief and abundant wetlands. The latter habitats are used by *C. horridus* as overwintering sites where snakes enter the water table to avoid desiccation and freezing temperatures (Burger, 1934; Kauffeld, 1957; Reinert and Zappalorti 1988a,b). By contrast, the high elevation, topographically rugged regions of northern Pennsylvania have limited wetland habitat, and the communal hibernation of *C. horridus* in rock ledges and deep crevices on mountain slopes is commonly reported (Martin, 1992; Brown, 1993). Despite these differences in general habitat and behavior, we found no differences in rates of cutaneous evaporative water loss or lipid content between shed skin samples from both locations. Few studies have addressed the issue of intraspecific differences in evaporative water loss, and this characteristic may have low intraspecific variability with respect to geographic distribution. It is noteworthy that,

during the active season, snakes from both populations appear to select structurally similar microhabitats within these two different forest environments (Reinert, 1993). Such interpopulation stability in microhabitat selection may be linked to physiological constraints associated with evaporative water loss. Because epidermal water loss patterns may be attributed to the microhabitat encountered by snakes during their activity period (Lahav and Dmi'el, 1996), differences in hibernation conditions do not appear to have influenced water loss rates.

Neonatal *C. horridus* shed skins exhibited a reduced rate of evaporative water loss and a higher lipid content when compared to adults. This finding parallels that of Ball (2004) who compared the percent lipid content of the shed epidermis of neonatal *Elaphe gutatta gutatta* with that of adults. By contrast, neonatal *C. viridis* reportedly had a greater rate of evaporative water loss and a lower percentage of extractable epidermal lipids prior to the first ecdysis (Graves et al., 1986). Likewise, the thickness of lipids in the mesos layer and the skin's resistance to "transepidermal" water loss were found to double after the first ecdysis in *Lampropeltis getula californiae* (Tu et al., 2002). Both Graves et al. (1986) and Tu et al. (2002) used *in vivo* experiments to compare neonates before and after the first ecdysis, but not neonates and adults. We did not have the available resources to examine the difference between first and second shed skins of *C. horridus*. It is possible that neonate *C. horridus* epidermis may be less permeable than adult epidermis, yet more permeable than second-shed epidermis. Although unlikely, such extensive ontogenetic fluctuation in lipid content and epidermal permeability could account for the apparent contradictions. Interspecific variation potentially reflects divergent phylogenetic histories and evolutionary pressures (Ball, 2004).

Although neonatal *C. horridus* have a lower rate of evaporative water loss per square area, our calculations of total body surface area and total body cutaneous water loss per volume showed that they have a higher relative rate of cutaneous water loss from their entire surface area. Previous studies have demonstrated that neonate or young colubrid snakes have greater whole-body cutaneous water loss and a lesser ability to resist desiccation than adults (Elick and Sealander, 1972; Dove et al., 1982). Such physiological changes may correlate with ontogenetic changes in habitat selection and aggregation behavior (e.g., Graves et al, 1986; Tu et al., 2002).

Neonatal *C. horridus* may be born with a more effective barrier to water loss than adults as an adaptation to their relatively higher total body water loss. Physiological reduction of evaporative water loss (e.g., maintaining cutaneous lipid concentrations) is not free of energetic costs and should only be selected for when it provides organisms with a survival advantage (Cohen, 1975; Winne et al., 2001). Consequently, the epidermis of adult *C. horridus* may be more permeable because the lower surface area-to-volume ratio of adults makes resisting desiccation less problematic. It should be noted that the quantity of lipids extracted is not necessarily correlated with permeability, because qualitative differences in lipids may also impart varying properties to the barrier to water loss (Roberts and Lillywhite, 1983). However, our results illustrate a strong corroboration of lipid content with evaporative water loss rates in both adult and neonate *C. horridus*.

Neonatal *C. horridus* are known to aggregate until the first ecdysis (occurring generally at 7–10 days) and then disperse (Klauber, 1972; Ernst, 1992; Martin, 1992). Such neonatal aggregations have also been reported for *C. viridis* (Duvall et al., 1985; Holycross and Fawcett, 2002), *C. adamanteus* (Butler and Hull, 1995), *C. molossus, C. lepidus,* and *C. scutulatus* (Greene et al., 2002). A possible explanation for such behavior is that aggregation limits evaporative water loss by reducing exposed surface area, which is especially important for the high surface area-to-volume ratio of neonates (Graves et al., 1986; Tu et al., 2002). Aggregation has also been implicated in

associating neonates with conspecific scents, especially when a mother is present (Duvall et al., 1985; Graves et al., 1986). *C. horridus* neonates have been documented to follow adult conspecifics to winter hibernacula, most likely by scent trailing (Reinert and Zappalorti, 1988b). Additionally, neonatal aggregations may serve to reduce predation by "diluting" predator effectiveness (Graves and Duvall, 1995), and the association with a mother may further deter predators. (Klauber, 1972; Duvall et al., 1985; Martin, 1992; Butler and Hull, 1995; Greene et al., 2002). Ultimately, it is unlikely that limiting evaporative water loss is the sole purpose for neonatal aggregations.

ACKNOWLEDGEMENTS

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Expression and Purification of a GST-tagged *Saccharomyces cerevisiae* protein Snu56 in *Escherichia coli*

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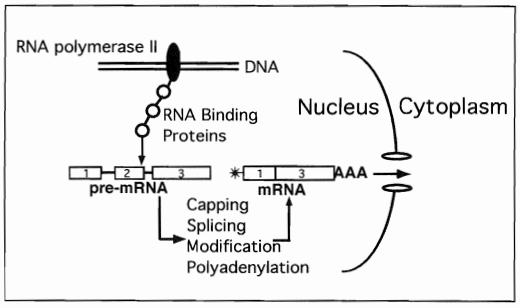
Abstract

The processing of mRNA in the nucleus and its subsequent transport into the cytoplasm is fundamental to eukaryotic gene expression and protein generation. Various different proteins in the nucleus combine to form complexes which temporarily bind to a pre-mRNA structure completing such necessary pre-mRNA maturation processes as capping, splicing, and polyadenylation. A *Saccharomyces cerevisiae* protein known as Snu56 is a component of such an mRNA maturation protein complex. The purpose of this study was to obtain pure Snu56p for antibody generation. Expression and purification of this Glutathione S-transferase tagged protein was accomplished in *Escherichia coli*. Purification protocol runs continually resulted in co-purification of the *E. coli* heat shock protein Hsp70. Attempts to elute off Hsp70 through cation exchange chromatography and modification of *E. coli* culture growth were employed. This review describes the success of Snu56 purification endeavors.

Introduction

The processing of mRNA in the nucleus and its subsequent transport into the cytoplasm is fundamental to eukaryotic gene expression and protein generation. For eukaryotes, the simple copying of the genetic information from a DNA template into an RNA transcript is the first step in messenger RNA synthesis (Proudfoot 2002). In recent years, evidence has emerged supporting that the messenger RNA processing reactions of acquiring a cap structure at the 5′ terminus, splicing out of introns within the pre-mRNA body, and the generation of a 3′ end modified by the addition of a poly (A) tail occur cotranscriptionally in the nucleus (Proudfoot 2002) (see Figure 1).

Figure 1. A schematic of pre-mRNA to mRNA maturation. RNA transcription and translation are not a coupled process. Freshly transcribed pre-mRNA must have several modifications made to it before it is able to cross a nuclear pore to find a cytoplasmic ribosome for translation. Various proteins in the nucleus come in and temporarily bind to the pre-mRNA structure completing such maturation processes as capping, splicing, and polyadenylation. Only after protein complexes complete such modifications is the pre-mRNA considered mature mRNA and able to cross the nuclear membrane to be transcribed into protein. Snu56 is a protein found in a splice of some protein complexes involved in mRNA maturation.



Initial transcripts of eukaryotic genes are interrupted by noncoding sequences called introns. In order to transform a newly transcribed pre-mRNA into a unit of functional information, mRNA splicing must occur (Proudfoot 2002). Accurate splicing in the nucleus is essential to the transport of mature mRNA to the cytoplasm for translation (Reddy 2001). Intron splicing of pre-mRNA is not only an important step in RNA processing, but also plays a key role in regulating gene expression (Reddy 2001). How an RNA

sequence is spliced determines the development and differentiation of multicellular organisms. Alternative splicing of the same transcript has the potential to produce structurally and functionally different proteins from a single gene (Reddy 2001). Illustrating the importance of the splicing step, 15% of all human genetic diseases are caused by mutations that either generate a new splice site on the RNA sequences or destroy existing, functional splice sites (Reddy 2001).

Ribonuclear proteins (RNPs) are complexes of one or more proteins with a short RNA molecule of about 60 to 300 nucleotides which function in modification and cleavage of pre-ribosomal RNA (Reddy 2001; Yong 2002). RNPs are present in all compartments of eukaryotic cells but RNPs which reside in the nucleus are called small nuclear RNPs (snRNPs). snRNPs assemble around a pre-mRNA body and temporarily bind to it enabling intron splicing. In *S. cerevisiae*, a protein component of such an snRNP is Snu56.

Past research found that SNU56, the gene responsible for Snu56 protein production in *S. cerevisiae*, interacts genetically with a component of the RNA export pathway. This lent support to the hypothesis that Snu56p may be a component of an RNA processing complex. Later, Snu56p was further classified as a component of the U1 snRNP. The U1 snRNP is essential for recognition of the pre-mRNA 5′-splice site and the subsequent assembly of pre-mRNA splicing complexes (Proudfoot 2002; Reddy 2001; Yong 2002). Yeast U1 snRNP has as many as 10 specific proteins associated with it, one of which is Snu56 (Gottschalk 1998). Snu56 is a 56kD protein consisting of 492 amino acids, relatively rich in serines and asparagines. Snu56p is positive and basic at physiological pH with an isoelectric point of 9.35. It has been established that without functional Snu56p, the splicing of all introns is affected (Gottschalk 1998).

The goal of this research effort was to obtain pure Snu56p for antibody generation. Expression and purification of this Glutathione S-transferase tagged protein was attempted in the model system *E. coli*. Several purification protocol runs resulted in co-purification of the *E. coli* heat shock protein Hsp70. With such results, the focus of this effort shifted from antibody generation to attempting to elute Hsp70 off Snu56p. Several protocol modifications such as cation exchange chromatography and altering *E. coli* culture growth were all employed. This review analyzes the success of each protocol modification in attaining pure Snu56p.

Experimental Procedure

Strains and Culture Conditions

Prior to this research effort, the fusion gene of a Glutathione S-Transferase (GST) tag and SNU56 had been generated. This fusion gene of GST tag and SNU56 was inserted into a plasmid vector marked with Carbycillin resistance. Plasmids which had accepted GST-SNU56 were selected for on Lureia Broth plates containing Carbycillin. Plasmid DNA was transformed into the *E. coli* strain BL21 genotype **F^-ompTgal[dcm][lon]hsdS_B(r_B-m_B-; an E.coli B strain**). *E. coli* cultures containing the GST-SNU56 fusion gene were grown in 400ml shaken Lureia Broth plus Carbycillin (1ug/ml) to mid log phase (OD = .6 A_{600}) at 37° C. Expression of the GST-Snu56 protein was induced with 0.1mM IPTG for four hours.

GST Purification Protocol

Culture Harvest

Post-four-hour induction, cultures were pelleted down in a 400ml bottle (6,000 rpm 20 min and cells resuspended in 25ml TBS (50mM Tris pH 8.0, 150mM NaCl). Cells were pelleted again (8,000 rpm 20 min) and resuspended in 12ml TBS + 0.5mM PMSF (24µL of a 0.25M stock). Six vials of such harvested culture samples were frozen at -80° C.

Cell Lysing and Protein Selection

Vials were thawed in a 30° C water bath. Once thawed, 0.75mL Triton X-100 to 1% (stock 20% in 50mM Tris pH 8.0) was rocked into the culture (4° C 20 minutes). Cells were lysed by French Press (2500 psi 20

min) and the whey centrifuged (18000 rpm 30 min) to spin down cell debris. Supernantant was rocked with 300 µL packed Glutathione Sepharose™ 4B beads (4° C 2 hours), which held affinity for the GST tag thereby selecting out the fusion protein by affinity chromatography.

Eluting Snu56p

The supernatant/bead mixture was pelleted (1300 rpm 2 min) with supernatant discarded and beads washed 2x's with 10 ml Solution A (100mM Tris pH 8.0, 120mM NaCl). Washed beads were then transferred to a micro centrifuge tube, washed once with Thrombin cleavage buffer, and resuspended in 500 µL Thrombin cleavage buffer. 5 µL of Thrombin were rocked into the resuspended beads (25° C 1 hour). Beads were then pelleted down, assumed now to be carrying only the GST tag and the supernatant containing thrombin cut Snu56p was saved. Supernantant fractions were dialyzed overnight in storage buffer (0.5 mM PMSF, 1mM DTT, 15% glycerol, 20mM Tris-HCL pH 8.0, 100mM NaCl, 2mM $MgCl_2$).

UV Spectroscopy

Overnight-dialyzed fractions were run through spectroscopy analysis to determine protein concentration at 260nm and 280nm in single-beam UV spectroscopy according to published protocols. Qualifications of protein content were performed using Bradford assay reagent (Bio-Rad) with BSA standard.

SDS-PAGE

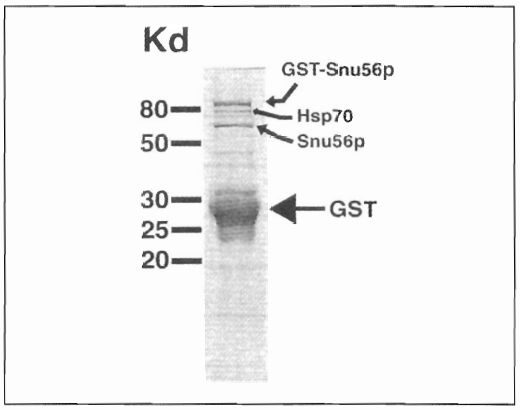
Gel electrophoresis was carried out according to published protocols using 10% SDS-PAGE and stained with Commassie Brilliant Blue. Samples ran for about 90 minutes at 120V.

RESULTS

First Purification

SDS-PAGE assay of the first GST Purification Protocol attempt yielded four bands when one band at the 56kD mark indicating purified Snu56 was expected (see Figure 2). The band running at about 80kD was determined to be the GST-Snu56 fusion protein and the large band falling at 20kD was determined to be the GST tag alone. Both bands were unanticipated. A band for Snu56 ran as expected but above it ran a band at about 70kD. Because of the molecular weight observed and the method of amplification used in this experiment, this band was determined to be the *E. coli* chaperone protein, Hsp70. From this gel, the focus of the experiment shifted from antibody generation to attempting to purify Snu56 from this *E. coli* chaperone protein.

Figure 2. 10% SDS-PAGE of the initial GST Purification Protocol attempt. GST-Snu65 fusion protein, Hsp70, Snu56, and GST tag all purified. The co-purification of Hsp70 set in motion a variety of protocol modifications to attempt to elute it off Snu56

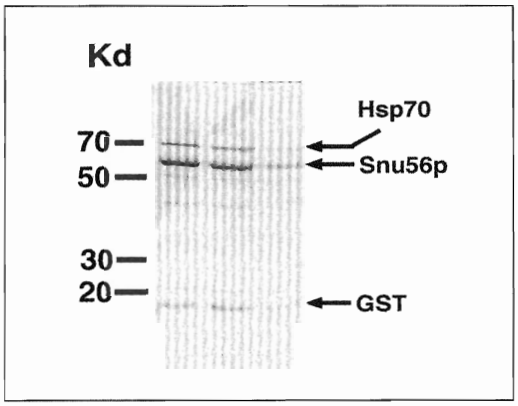


Ion Exchange Chromatography

Snu56 has an isoelectric point of 9.37 while Hsp70 has a pI of about 4. Both Snu56 and Hsp70 carry a positive charge at physiological pH but their charges vary enough that separation of the two by ion exchange chromatography was plausible. Thrombin cut Snu56 protein fractions after overnight dialysis in storage buffer were run through a cation exchange column (DEAE Sepharose Fast Flow) in an attempt to elute Hsp70 off Snu56 by its isoelectric point. 400µl of packed resin were placed in a column and washed two times with 0.5ml buffer A (50mM Tris-HCl 8.0, 0.1mM EDTA, 2µl Bmercaptoethanol, 10ml glycerol, 37.5ml dH_2O). The thrombin cut Snu56 protein fraction was sent through the column twice. The resin was then washed with three different buffers applying an increasing step gradient of NaCl concentration.

Three 0.5ml washes of Buffer A were sent through followed by three 0.5mL washes of 20% Buffer B and finished with three 0.5ml washes of Buffer B (50mM Tris-HCl 8.0, 0.1mM EDTA, 2µl Bmercaptoethanol, 10mM glycerol, 4ml NaCl, 23.5 dH_2O). Column runs were carried out at 4° C and all washes were collected. UV spectroscopy at 260nm and 280nm revealed that any protein retrieved off the column was localized to the elutions with Buffer B. The last three column washes of Buffer B were analyzed using 10% SDS-PAGE to see if there was any lessening in Hsp70's presence. Hsp70 continued to co-purify with Snu56 (Figure 3).

Figure 3. 10% SDS-PAGE gel of last three cation exchange column washes with high salt Buffer B. Snu56 and Hsp70, although having significantly different isoelectric points, bound to the column and eluted off together. This confirmed hypotheses that Snu56 was associated with Hsp70.



Discussion

In order to study proteins, it is often necessary to obtain a large quantity of the protein of interest. Protein expression in *E. coli* allows for high rate protein generation (Saluta 2002). A eukaryotic protein of interest is tagged and cloned into a prokaryotic plasmid. The protein of interest along with its associated tag is called a fusion protein. Often, expressing a large foreign protein complex like a fusion protein in *E. coli* requires chaperones to assist the protein in folding correctly.

The ensemble of molecular chaperones constitutes the cellular system for *de novo* folding of freshly translated proteins (Saluta 2002; Tomoyasu 2001). In *E. coli*, chaperone DnaK and its co-chaperones DnaJ and GrpE assist the *de novo* folding of at least 340 cytosolic proteins within a broad size range of 16 to 167kD (Tomoyasu 2001; Yoshimune 2002). The function of chaperones in ensuring the integrity and high quality of protein structure relies on their ability to refold misfolded proteins. Chaperones are always operative but become particularly important under stress conditions to the cell, in particular, heat shock (Tomoyasu 2001). The class of chaperones which includes the DnaK protein are the 70kD heat shock proteins. DnaK is the prokaryotic homologue of Hsp70 (Yoshimune 2002). Hsp70, a highly conserved heat shock protein, is found in almost all organisms (Yoshimune 2002) to assist in the folding of freshly translated polypeptides. Chaperones 70 reversibly bind unfolded proteins by ATP hydrolysis (Crouy-Chanel 1999).

Attempts to elute Hsp70 off Snu56 utilizing its isoelectric point in a cation exchange column were unsuccessful. It was anticipated that Hsp70 would remain attached to the negative resin while Snu56 would run through. In actuality, Hsp70 and Snu56 attached to the column together and co-eluted with high salt. Results confirmed hypotheses that the two proteins were associated and possibly became so during Hsp70 assisting Snu56 in folding.

ATP hydrolysis powers the chaperone activities of Hsp70. Hsp70 interacts with a protein substrate in an ATP-dependant manner to prevent aggregation and promote protein folding by the ATP hydrolysis cycle (McCarty 1995). The tight association of ATPase activity with substrate binding is essential to the chaperone activity of Hsp70. The unfolded substrate stimulates ATPase after binding to the preformed Hsp70-ATP complex. The Hsp70-ATP-substrate intermediate is characterized by rapid dissociation of bound substrate, but this transition state can be stabilized by hydrolysis of the Hsp70 bound ATP. In the losing of the gamma phosphate, the ADP-Hsp70 becomes tightly bound to the protein substrate rather

than transient (McCarty 1995). ADP bound Hsp70 prevents the dissociation of bound substrate. When ATP is hydrolyzed to ADP, the chaperone-substrate dissociation rate is lowered and stability increased (McCarty 1995). Such was the case believed to be occurring with Snu56 and Hsp70.

Cell cultures available at the start of this purification effort had been grown at the optimal condition of 37° C and induced for four hours. Previous studies suggested that a lower induction time could lessen the chances of Hsp70 being associated (Reddy 2001). By expressing Snu56 for $\frac{1}{4}$ and $\frac{1}{2}$ the time called for in the original protocol, the hypothesis stood that the *E. coli* cellular system would not be overwhelmed with foreign protein and Hsp70 would not have to be called in to assist in the folding of Snu56. High rate over-expression of a protein has been linked to Hsp70 binding. The over-expression of Snu56 in *E. coli* may have caused its association with Hsp70.

Culture growth applying lower induction times was attempted. SDS-PAGE analysis of purifications revealed a decrease in the presence of Hsp70 but fractions ran very dirty with background proteins (results not shown). This was attributed to the fact that the original volume of Glutathione Sepharose beads in the affinity chromatography step of the protocol was used even though a lower concentration of GST-Snu56p was now present in purified fractions. It is hypothesized that after binding the GST-Snu56 fusion protein, the sepharose beads began to bind additional miscellaneous proteins. Culture growth modifications succeeded in lessening the presence of Hsp70 but complicated purifications by co-purifying various other proteins.

Conclusions

Expression and amplification of a eukaryotic protein in the prokaryotic system *E. coli* is a widely used and accepted protocol. Tagging by a Glutathione S-transferase tag is a popular tagging method associated with high success in attaining a clean purification of a protein of interest. The GST tag in this research effort proved highly unsuccessful in purification attempts of Snu56 from the Hsp70 chaperone component found in *E. coli*. Modifications made late in the original protocol such as cation exchange chromatography and culture growth modifications produced no success in eluting off Hsp70.

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Effect of Progesterone Induced Blocking Factor (PIBF) on Pregnancy Rates

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Abstract

Progesterone induced blocking factor (PIBF) is thought to be a protein involved in the suppression of the cell-mediated immunity in pregnant women, which prevents the destruction of the fetus during pregnancy. As such, it was expected that the absence of PIBF expression in lymphocytes would lead to a rise in spontaneous abortions in pregnant women. To test this, blood samples were taken from pregnant women, and lymphocytes were extracted and tested for the presence of PIBF. The women were subsequently monitored for the remainder of their pregnancy and spontaneous abortions were recorded. It was determined that a greater proportion of women without PIBF expression had spontaneous abortions than those expressing PIBF. In order to induce the expression of PIBF and increase pregnancy rates, several procedures are being tested including Lymphocyte Immunotherapy (LI), and Intravenous Immunoglobin treatment (IVIG). Additionally, certain cancer cells lines appear to excrete PIBF, making PIBF suppression a potential tool in fighting cancer.

Introduction

The fetus is a semiallograft (partially foreign substance) because of the presence of paternal antigens on its surface (Check et al. 1996). As such it would be expected that some aspect of the body's immune system would recognize the fetus as foreign and respond accordingly. This occurs during spontaneous abortion (miscarriage) when fetal products are invaded by elements of the cellular immune system, typically the natural killer cells rather than cytotoxic T-cells. The lack of cytotoxic T-cells in both healthy and miscarried fetuses could possibly be attributed to an absence of antigen in the context of MHC I, a complex necessary for the activation of cytotoxic T-cells (Check 2003). However, the absence of natural killer cells attacking the fetus in healthy pregnancies does not have a generally acknowledged mechanism.

Progesterone is a vital hormone for the maintenance of pregnancy before the formation of the placenta (Check 1987). As a result, progesterone is found in high quantities at the fetal-maternal interface at the beginning of the pregnancy (Check et al. 1997). Any allogenic substance, one containing an antigen from the same species as the host (Goldsby et al. 2003), is capable of generating progesterone receptors in gamma delta T-lymphocytes (Check 2003). Gamma delta T-cells are known to have secretory, as opposed to cytotoxic, activity in the body (Goldsby et al. 2003). It has been demonstrated that one secretion of gamma delta T-cells, when in the presence of high levels of progesterone, is a 34 kDa protein, labeled progesterone induced blocking factor or PIBF (Szekers-Bartho 1985). In an experiment adding natural killer cells to k562 tumor cells, the further addition of PIBF prevents the natural killer cells from destroying the tumor cells (Check 2003).

As a result of the preceding information, the following theory regarding the protection

of the fetus from natural killer cells has been proposed. It is suspected that the CD8+ T cells in the vicinity of the fetus generate progesterone receptors in response to the fetus. High levels of progesterone, present in that area of the body only, make contact with those receptors generating a signal transduction pathway that ultimately leads to expression and excretion of PIBF in at least some of the cells. This release of PIBF prevents natural killer cell activity in and immediately around the fetus, but, as a result of its localized nature, does not retard defense against infection from pathogens in the rest of the body. In this way, the immune system is prevented from destroying the fetus but can still act as a barrier against disease.

In order to test whether PIBF is partially responsible for preventing spontaneous abortion by suppressing natural killer cell activity, blood was drawn from pregnant women and analyzed to see if PIBF was expressed in lymphocytes present in the blood. Subjects were monitored throughout their pregnancy, and spontaneous abortions over the course of the pregnancy were recorded. It was expected that more women would spontaneously abort who did not express PIBF than did express the protein.

METHODS

Slide Preparation Procedure:

From May 29 until August 8, at the Cooper Center for In-vitro Fertilization in Marlton, an additional tube of blood was taken from all pregnant women given pregnancy (Beta) tests, starting at their third test and continuing until the twelfth week of pregnancy. Samples were collected in labeled heparin tubes, and lymphocytes were extracted using the following procedure within 24 hours of collection of the samples. The tubes of blood were rested to allow for separation of the plasma layer from the blood.

Labeled conical tubes were partially filled with Isoprep, a chemical used for the separation of lymphocytes. The plasma was aspirated from the heparin tubes and carefully placed in a corresponding conical tube, layered above the Isoprep. Tubes were then filled to the top with Hanks Balanced Salt Solution and spun in a centrifuge to allow red blood cells, clotting factors, and other unwanted particles to travel to the bottom of the tubes. The lymphocytes could not permeate the Isoprep and formed a cloudy layer directly above the Isoprep.

Lymphocytes were extracted, taking care to not disturb the Isoprep layer (as it was toxic to lymphocytes) and placed in new conical tubes, submerged in an ice water bath to preserve the lymphocytes. The tubes were filled with cold Hanks and spun repeatedly in a refrigerated centrifuge to clean and purify the samples. After the final spin, the pellets were resuspended with Hanks. Labeled slides were loaded along with cytofunnels onto a slide centrifuge and the appropriate samples were added to the appropriate cytofunnels. Slides were left to dry overnight.

The slides were washed in cold isopropyl alcohol for five minutes, let dry for 15 minutes, and then washed in cold Phosphate Buffered Saline (PBS) for five minutes. Upon drying (two to three hours), slides were stored in folders and frozen as a safety precaution.

Slide Staining and Reading Procedure:

To begin the staining procedure, the slides were removed from the freezer, etched around the sample with a glass cutter, and rehydrated in PBS. Included in each batch was at least one positive control. The slides were then subsequently washed in hydrogen peroxide solution in order to eliminate remaining erythrocytes and other impurities. Slides were then washed again with PBS and wiped dry around the etched area. Protein-blocking agent (PBA) was then added to each slide to prevent any protein present from reacting to the stain and left to incubate. After PBA was removed, antibody control was added to the positive control slide(s), to make completely certain that they tested positive for PIBF. Rabbit anti-PIBF antibodies were added to each slide, and let set overnight.

The slides were tipped off and washed with PBS so that the anti-PIBF antibodies would only remain on the cells with PIBF. Anti-rabbit peroxidase was added to each slide, in order to aid with the color development. After an incubation period, the anti-rabbit peroxidase was removed and the slides were washed with PBS. An AEC chromagen developer solution was prepared, added to each slide and allowed to incubate until the background developed. After developer was removed and slides were rinsed, slides were placed in hematoxylin counterstain. The hematoxylin was removed, and slides were rinsed, dried, mounted with a cover slip, and allowed to dry overnight.

Slides were read using oil immersion and 300 lymphocytes were counted per slide. Slides with lymphocytes testing positive for PIBF led to a given sample being considered PIBF positive. The anti-PIBF antibody used was polyclonal in nature, preventing the quantity of PIBF in a given sample from being precisely recorded. To improve accuracy, only slides with 300 readable cells, and samples that corresponded to Beta results of greater than 10,000 were analyzed.

Table 1

Sample	IVF	Date Collected	PIBF	Beta Result	Beta #	Miscarriage
A	yes	16-Jun	yes	14922	3	
B	yes	24-Jun	yes	71983	4	
C	yes	11-Jul	yes	187305	6	
D	yes	14-Jul	yes	126726	7	
E	no	24-Jun	no	105835	7	
F	yes	1-Jul	yes	156648	9	
G	yes	23-Jun	no	28156	8	Yes
H	no	16-Jun	no	66541	6	
I	no	24-Jun	no	93844	8	
J	yes	14-Jul	yes	62763	4	
K	yes	25-Jun	yes	55267	4	
L	yes	2-Jul	yes	110543	5	
M	yes	23-Jun	yes	11664	4	
N	no	14-Jul	no	116015	7	
O	no	14-Jul	no	67724	5	
P	no	14-Jul	yes	53448	6	Yes
Q	no	17-Jul	no	324058	7	
R	yes	17-Jul	yes	83486	6	
S	yes	23-Jun	no	144412	7	
T	no	17-Jul	no	85990	6	
U	no	14-Jul	yes	108183	8	
V	no	2-Jul	yes	124416	7	
W	no	14-Jul	yes	109453	9	
X	no	14-Jul	no	72914	3	Yes
Y	yes	14-Jul	no	107970	7	
Z	yes	1-Jul	yes	56202	5	
AA	yes	14-Jul	no	89160	7	Yes
BB	yes	17-Jul	no	60844	6	
CC	yes	1-Jul	yes	10117	4	
DD	yes	1-Jul	yes	183094	6	

Results of PIBF, pregnancy test, and other relevant patient and sample information collected between 5/29/03 and 8/8/03. Names were not used because of Hippa regulations respecting the privacy of patients. Miscarriage data were provided for the purpose of comparing the rates of successful pregnancies in PIBF- positive and negative women. Absence of response in that category indicates that the subject who produced the sample had not miscarried but the pregnancy had not yet come to term. Additional information (date collected, whether patient conceived through in-vitro fertilization (IVF), etc.) was provided as background.

RESULTS

Careful record was kept of every blood sample processed into a slide, stating both the name of the patient and the date of collection. Upon reading of slides, which were also marked with the name and date of collection, the presence or absence of PIBF was recorded separately. To create Table 1, the information from the two files was combined along with information from each patient's chart.

From study of Table 1, it was determined that one of the 17 samples that tested positive for PIBF came from women who eventually miscarried, while three of the 13 samples that tested negative for PIBF resulted in miscarriages. In percentages, only 5.9% of women testing positive for PIBF miscarried, while 23.1% of women testing negative for PIBF miscarried. Unfortunately, the sample size proved inadequate to demonstrate significance using a chi-squared analysis, because of the requirements of that calculation.

The goal of this experiment was to demonstrate the link between PIBF and successful pregnancy by showing that more women expressing PIBF had successful pregnancies than those not expressing PIBF. The project was successful in tentatively determining this link, as women who failed to express PIBF were almost four times as likely to miscarry as women who expressed PIBF. However, in order to establish the link concretely, another project with a sample size large enough to demonstrate statistical significance will be necessary.

A sample expressing PIBF came from a woman who eventually miscarried; in addition, several PIBF negative samples came from women who had successful pregnancies. There are many potential reasons for the

PIBF positive woman to have miscarried: even if she did not have an immunological defect, she or her partner could be suffering from any of a myriad of infertility causes. Many such difficulties are solved through repeated attempts with in-vitro fertilization, an option that the couple had not yet chosen.

The PIBF negative women who have not miscarried are indicative of the involvement of factors other than PIBF in preventing the invasion of natural killer cells. Much is still not known regarding the complete process by which natural killer cells are prevented from entering the body. As a result, it is quite possible that other proteins can act in a similar manner to PIBF and lead to the inactivation of natural killer cells. These proteins could potentially be secreted from gamma delta T-cells or another source or sources, and some could possibly provide a supporting role to PIBF, aiding it in inactivating natural killer cells. Another possibility is that one or more of the proteins act in a way analogous to PIBF and only when all such proteins are absent does infertility occur. As other blocking factors are discovered along with their interactions with PIBF, the role of PIBF in pregnancy will be elucidated.

Discussion

This experiment has asserted a positive correlation between expression of PIBF in lymphocytes and success of pregnancy; hence, any treatment that would lead to expression of PIBF in PIBF negative women would be beneficial. According to the proposed mechanism for the creation of PIBF, there appear to be two primary reasons for it not to be expressed in a pregnant woman. One reason is a lack of progesterone because the hormone must fill the progesterone receptors in order for gamma delta T-cells to produce PIBF. The other is that the fetus is not sufficiently allopathic to induce the gamma delta T-cells to produce the progesterone receptors in the first place. As a result of the importance of progesterone in reproduction aside from the expression of PIBF, progesterone levels of pregnant women are already closely monitored, and supplements are given when levels decrease. However, it is not standard practice to ensure that the gamma delta T-cells make progesterone receptors. This leaves the possibility that spontaneous abortions in PIBF negative women may be solved by inducing such receptors with a sufficiently allopathic substance.

It is believed that lymphocytes are 100 to 1,000 times as immunogenic as the fetus (Check 2003). As a result, several studies have been conducted in an attempt to gage what, if any, effect Lymphocyte Immunotherapy (LI) has had on pregnancy outcome, as well as expression of PIBF in women. The source of the lymphocytes used in LI was typically the husband to reduce risk of possible infection (Check et al. 1995). Because of the immensely immunogenic nature of lymphocytes, those coming from the husband were considered to be sufficiently immunogenic to cause a response, even though paternal antigens on the fetus were not.

Several studies have demonstrated that LI improves pregnancy rate and outcome over control (Check et al. 1995). One study reviewed all embryo transfers conducted over a 3.5-year period, comparing those who received LI to all others. The clinical pregnancy rate was 38.3% for the LI patients compared to 28.7% for the rest. The live delivery rate was even more impressive with 30.8% of the LI patients delivering while only 19.7% of the control went to term (Liss et al. unpublished). Another study compared women undergoing LI in addition to progesterone therapy with women only undergoing progesterone therapy. Of the women who received LI, 65.7% became pregnant while only 45.1% did so who received progesterone alone. Even more compelling was that only 26% of those 65.7% miscarried, while 57.1% of the progesterone group did so (Check et al. 1995).

Having documented the beneficial effects of LI in regards to pregnancy, it would be expected that LI would become more and more frequently used to prevent destruction of the

fetus by natural killer cells. Unfortunately, a poorly conducted experiment served to remove LI as a tool in fertility. It has been documented that, for an unknown reason, the lymphocytes used in LI actually reduce pregnancy rates when refrigerated prior to injection. Unfortunately, an NIH-funded experiment testing the usefulness of LI used refrigerated lymphocytes and, as was to be expected, pregnancy rates were significantly lower than control (Check 2003). Unaware that refrigeration was a confounding variable, the FDA took the step of requiring that LI be approved as an investigational new drug before further use is allowed. The cost of the testing required for such an approval is astronomical; as a result, LI is no longer performed in the United States, though some patients travel to Mexico to undergo the treatment.

With Lymphocyte Immunotherapy no longer available for use to combat infertility in the United States, an alternative immunogenic source is needed to induce gamma delta T-cells. Intravenous Immunoglobin (IVIG) treatment is thought by some to be the successor to LI. IVIG treatments involve the intravenous insertion of a conglomeration of sera containing antibodies from numerous individuals. Drawbacks are the possibility of infection as well as cost; IVIG treatments are approximately 10 times as expensive as LI and, because of their experimental nature, are rarely covered by an insurance company. However, IVIG is considered by some to be even more effective at preventing miscarriage than LI (Check 2003).

The first study conducted regarding IVIG was conducted among women who had failed to achieve pregnancy with IVF and appeared to have abnormal natural killer activity. Of these women, 63% undergoing IVIG treatment achieved pregnancy while only 4% of the control group did so (Fisch et al. 2002). Subsequent studies are needed to confirm these most impressive results. Unfortunately, because of the expense of IVIG, there are often not enough patients able to take advantage of the treatment to make for statistically significant findings. In fact, the original topic for this research paper was to compare PIBF expression in IVIG patients versus control. The focus was altered as there was only one IVIG patient who conceived for the duration of the summer. Happily, the patient, in spite of more than three previous spontaneous abortions, has had a healthy pregnancy thus far. If the success stories of IVIG continue, there may eventually be a large enough sample size to prove its effectiveness statistically.

Because of its role in fertility and the immune system, PIBF is a unique and interesting protein, worthy of all the research that has been conducted to learn about it. In addition, there are strong indications that PIBF plays an important role in a largely unrelated field, oncology. At first, it would appear that there is no relationship between the fields; however, the similarities become clear under closer inspection. Spontaneous abortion is similar in many ways to remission of a cancerous tumor. This is because both tumors and fetuses are semiallopathic organisms that must evade the cellular immune system in order to survive. Thus, it is quite possible that in a mechanism similar to the one used to protect the fetus, certain cancer cell lines express PIBF to prevent the cell-mediated immune system from destroying tumors.

Many tumors have been documented to produce human chorionic gonadotropin, a hormone responsible for progesterone production (Check 2001). As a semiallopath, tumors should be able to stimulate progesterone receptors in gamma delta T-cells. Theoretically, with the high progesterone levels that should be present in the area around tumors secreting chorionic gonadotropin, the CD 8+ T-cells should produce PIBF, rendering the natural killer cells in the area ineffective. Research is currently under way testing to see if certain cancer cell lines express PIBF to evade the natural killer cells; early evidence appears to support that hypothesis.

If it is proven that certain tumors express PIBF, suppression of the progesterone required for PIBF secretion, suppression of

PIBF directly, or targeting of the tumor through PIBF may prove to be effective means of fighting cancer. Progesterone suppression could be brought about through preventing chorionic gonadotropin from being produced or rendering it inactive by injecting anti-chorionic gonadotropin antibodies. Also, a competitive inhibitor for the chorionic gonadotropin receptor that leads to the production of the progesterone could be introduced. If progesterone is allowed to be made, PIBF production could be inhibited through use of a progesterone receptor antagonist. An anti-PIBF antibody could serve to render PIBF inactive and unable to inhibit the function of natural killer cells. Finally, a radioactive or toxic chemical could be linked to an anti-PIBF antibody. This would serve to target only the tumor, as PIBF is not produced in normal tissue in men and non-pregnant women.

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Expression of *rab8* in Transgenic *Xenopus laevis* Photoreceptors

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Abstract

Rab8 is a small GTPase involved in membrane trafficking in rod photoreceptor cells. It cycles between GDP- and GTP-bound states and is thought to play a role in the transport of rhodopsin, the photopigment present in rod cells, from its site of synthesis to its site of function. Previous studies have shown that when mutant forms of the canine *rab8* gene are expressed in *Xenopus laevis* rods, they interfere with the intracellular transport of rhodopsin and ultimately induce apoptosis of the rod cells (Moritz et al., 2001). Although the *rab8* sequence is highly conserved among species, there are 10 amino acid differences between the canine and *Xenopus* Rab8 proteins. To determine whether such species variation has an effect on the function of the protein, this study compared the effects of expression of canine *rab8* with the effects of expression of *Xenopus rab8* in transgenic *X. laevis* rods. Wild type *X. laevis rab8* cDNA was obtained by RT-PCR from retinal mRNA, and mutant forms were created by site-directed mutagenesis. Each *rab8* gene was attached to a rod-specific promoter (Xop) and expressed as a green fluorescent protein (GFP)-fusion protein to allow for its detection *in vivo*. Transgenic tadpole retinas were studied using confocal microscopy. There were no phenotypic differences between the expression of canine and *Xenopus rab8* in *X. laevis* rods. Both wild type proteins localized to rod inner segments, and both mutant forms induced rapid death of the rod photoreceptor cells.

Introduction

Vision is made possible by the retina's ability to convert light energy into nerve impulses that the brain interprets as an image. This process begins with the rod and cone photoreceptor cells, the light-sensitive neurons of the retina. Rods and cones are highly polarized structures that have an outer and inner segment joined by a connecting cilium. The outer segment contains photopigment that absorbs light, and the inner segment contains the cell nucleus and leads to the synaptic terminals. Rhodopsin, the photopigment present in rod photoreceptor cells, is synthesized in the rough endoplasmic reticulum of rod inner segments and transported via the connecting cilium to the membranous disks of rod outer segments (Young, 1976). Once in the outer segment, rhodopsin absorbs light energy, changes its conformation, and initiates the biochemical cascade that transduces light into electrical signals. The rhodopsin-containing disks of rod outer segments are continually renewed; each disk formed at the base of the rod outer segment soon migrates toward the tip and is shed (Young, 1976). As well as requiring extremely high rates of membrane and protein synthesis (Besharse, 1986), this renewal process also requires the transport of 50,000 molecules of rhodopsin every minute from rod inner to outer segments (Papermaster et al., 1975). Eukaryotic cells have evolved efficient mechanisms of membrane trafficking to meet these intracellular transport demands. Although its role is not precisely known, Rab8 has been shown to

be a key component of the membrane trafficking mechanisms that regulate intracellular rhodopsin transport in rod cells (Moritz et al., 2001).

Rab8 is a GTPase protein that cycles between GDP- and GTP-bound states and thus acts as a molecular switch in intracellular vesicular transport. GTP-bound Rab8 is active and associates with rhodopsin-containing vesicles (Deretic et al., 1995). After Rab8 hydrolyzes GTP to GDP, the vesicles are able to fuse at their docking site at the base of the connecting cilium, and rhodopsin can then be transported along the cilium to its site of function in the outer segment (Moritz et al., 2001). GDP-bound Rab8 is inactive; it cannot associate with the vesicles transporting rhodopsin or facilitate their fusion to the plasma membrane.

Previous research has shown that in the frog *Xenopus laevis,* mutant forms of canine Rab8 cause death of the rod photoreceptor cells (Moritz et al., 2001). A dominant negative mutant in which threonine is replaced with asparagine in the sequence of amino acids (Rab8-T22N) cannot exchange its bound GDP for GTP and is locked in its inactive conformation. Always GDP-bound, canine Rab8-T22N is unable to associate with the rhodopsin-containing vesicles, and its expression in *Xenopus* rods inhibits the vesicles from fusing at their docking site (Moritz et al., 2001). This creates a roadblock in the transport of rhodopsin from the inner to outer segment and induces apoptosis of all but the peripheral rods (Moritz et al., 2001). Another mutant form of canine Rab8, in which glutamine is replaced with leucine (Rab8-Q67L), is constitutively active and can no longer hydrolyze GTP to GDP. This mutant also induces retinal degeneration in *Xenopus* rods, but not as quickly or severely as does canine Rab8-T22N (Moritz et al., 2001). The precise role of Rab8 in rod cells, as well as the mechanisms by which its mutant forms induce apoptosis, is not yet clearly understood.

Although the Rab8 sequence is highly conserved, there are 10 amino acid differences between the canine and *Xenopus* Rab8 proteins. Since the possibility exists that these subtle changes could affect the function of the protein, it is possible that rod cell death induced by the mutant canine Rab8 was the result of species differences alone. Therefore, it is the purpose of this study to compare the observations obtained using the canine *rab8* gene (*crab8*) and its mutants with an endogenous *Xenopus rab8* gene (*xrab8*) and its mutants in transgenic frogs expressing the transgenes in rods.

Because the region of Rab8 activity in *X. laevis* is only accessible *in vivo* (Papermaster, 2002), green fluorescent protein (GFP) was attached to the N-terminal of Rab8 to allow for its detection in live frogs. In this experiment, wild type and dominant negative mutant (T22N) forms of *crab8* and *xrab8* were expressed as GFP-Rab8 fusion proteins in the rods of transgenic *X. laevis* tadpoles. This allowed for the direct comparison of the effects of expression of canine and *Xenopus rab8* genes under the physiological conditions of an *in vivo* experiment. Results obtained from this experiment are consistent with previous work on *rab8,* and demonstrate that mutant forms of *rab8* reproducibly induce rod cell death in transgenic frogs. Knowledge gained through these experiments will serve as a foundation for subsequent investigations of other components of membrane trafficking and protein transport in photoreceptor cells. In addition, because the retina of frogs contains approximately the same proportion of rods and cones and is similar in structure to the human retina, these experiments also provide an excellent experimental model of human blindness.

MATERIALS AND METHODS

Mutagenesis and Plasmid Preparation

Polymerase chain reaction (PCR) was used to introduce the T22N mutation into *Xenopus* wild type *rab8* cDNA. Four primers were used: two flanking the 600 bp *rab8* gene and two internal primers containing the desired T22N mutation. The *xrab8*-T22N PCR product was then ligated into a pCR4 plasmid

using TOPO Cloning Kit™ (Invitrogen) and transformed into One Shot TOP 10 Chemically Competent™ *E. coli* (Invitrogen). The pCR4-*xrab8* plasmids were isolated from bacterial cells using QIAprep Spin Miniprep Kit™ (Qiagen) and sequenced to confirm the presence of the desired T22N mutation in the *xrab8*-T22N cDNA. Each *rab8* insert was then subcloned from the cloning vector (pCR4) into the *EcoRI/BamHI* sites of a Xop expression vector that contained a 1.3 or 5.5 kb fragment of the *Xenopus laevis* rhodopsin (Xop) promoter (to drive expression in rod cells) and GFP cDNA. The isolation of the desired Xop-*xrab8*-wt and Xop-*xrab8*-T22N plasmids was verified by sequencing. Plasmids were linearized using the restriction enzyme *NotI* in preparation for transgenesis.

Transgenesis

Transgenesis, a procedure used to introduce exogenous DNA segments into the germ line DNA of an organism, was used to generate *rab8* transgenic tadpoles by a modified technique (Kroll and Amaya, 1996). DNA constructs were diluted to 150 ng/µl using spectrophotometric analysis, then combined with prepared *Xenopus* sperm nuclei and a reaction mix that allowed the transgene to integrate within the genomic DNA. Transgenic sperm nuclei were injected into the central dorsal pigmented region of condensed chromatin in dejellied *Xenopus* eggs. Eggs were incubated on 2% agarose well plates in a 0.4x MMR/6% Ficoll solution at 18° C until embryos reached the 4-cell stage. All embryos with perfect or near-perfect division symmetry were transferred to a 0.1x MMR/6% Ficoll solution and allowed to develop overnight at 18° C. The following day, all surviving embryos were transferred to 8-liter tanks containing 0.1x MMR and G418. Tadpoles were raised on a 12-hour light/12-hour dark cycle at 18° C and fed a 50:50 mixture of powdered NASCO™ frog brittle (Fort Atkinson, WI) and powdered frog chow (Rangen, Buhl, ID). Tadpoles were screened for GFP expression at five days post fertilization (dpf) using a Leica™ MZ8 dissecting microscope equipped with standard epifluorescence optics and GFP filter sets. Transgenic tadpoles were easily identified by the green fluorescence emitted from their eyes.

Fixing, Sectioning, and Staining Retinas

Fourteen- and 21-day-old tadpoles were fixed in 0.1 M sodium phosphate, pH 7.5, containing 4% paraformaldehyde and stored at 4° C. Eyes were removed from tadpoles and embedded in OCT medium (Tissue Tek). Frozen samples were sectioned using a cryostat into 10 µm thick sections. Slides were stained with Hoechst 33324™ dye (Sigma-Aldrich) and Texas-Red Conjugated Wheat Germ Agglutinin™ (TR-WGA, Molecular Probes) to label the nuclei and Golgi pathways of vesicular transport, respectively. A Zeiss 510 LSM™ confocal microscope (Carl Zeiss, Thornwood, NY) was used to analyze the expression of the GFP fusion proteins in all sections.

RESULTS

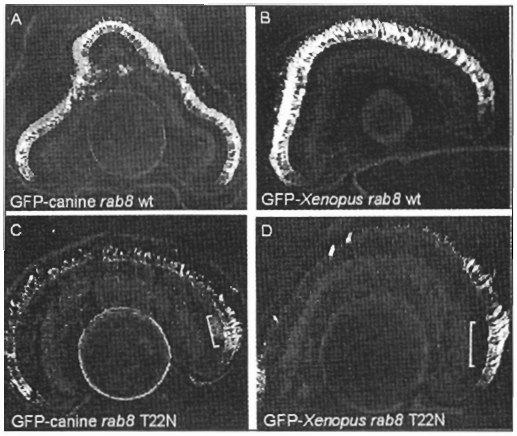
Creation of Transgenic Tadpoles

Of about 2,500 injected eggs in each transgenesis experiment, approximately 100 embryos survived beyond 5 dpf. Transgenic tadpoles expressing GFP-*crab8*-wt and GFP-*xrab8*-wt were easily detected by the green fluorescence emitted from their retinas. Green fluorescence was also visible in the eyes of tadpoles expressing canine and *Xenopus* GFP-*rab8*-T22N, but was limited to the peripheral rods by 13 dpf, as indicated by a lack of fluorescence in the central retina. The localization of GFP-*rab8* constructs within rods was further studied using confocal microscopy.

Confocal Images of Transgenic Tadpole Retinas

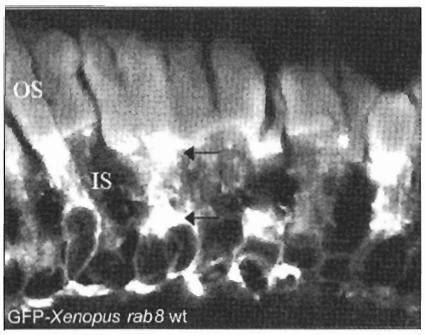
Transgenic tadpole retinas were fixed, sectioned, and stained in order to analyze the localization of GFP-*rab8* fusion proteins. All areas of *rab8* expression fluoresced green because of the attached GFP molecule (which emits green fluorescence upon excitation by blue light), and rod outer segments appeared red as a result of labeling by Texas-Red WGA™.

Figure 1: Confocal images of transgenic tadpole retinas (10 µm sections). Transgenic tadpole retinas expressing *crab8*-wt (A), *xrab8*-wt (B), *crab8*-T22N (C), and *xrab8*-T22N (D). GFP-Rab8 fusion proteins are indicated by bright areas. Lack of uniformity in GFP expression in the canine *rab8* wt section (A) results from damage caused prior to sectioning. GFP-*rab8*-T22N fusion protein is expressed in a retina with severe retinal degeneration; only peripheral rods (indicated by brackets) have survived (C, D).



All GFP-Rab8 fusion proteins localized to rod inner segments. There were no phenotypic differences between retinas expressing wild type canine *rab8* and wild type *Xenopus rab8*. Both retinas had uniform and high levels of expression throughout the inner segment of all rod cells. The expression of *rab8*-T22N, however, was limited to the inner segment of peripheral rods. As with the wild type proteins, there were also no apparent differences between the mutant canine *rab8*-T22N and its *Xenopus* counterpart; both forms induced severe retinal degeneration. To investigate *rab8* localization *within* individual rod photoreceptor cells, higher magnification confocal images were taken.

Figure 2: Confocal image of GFP-*xrab8*-wt localization in 21-day-old transgenic tadpole retina (10 µm sections). GFP-Rab8 fusion proteins are indicated by bright areas; OS = rod outer segments, IS = rod inner segments; cell nuclei are represented by dark regions within the inner segment. Brighter areas of fluorescence (arrows) indicate greater expression levels of *rab8*.



Higher magnification revealed that all Rab8 fusion proteins localized to rod inner segments, especially to the Golgi apparatus, synapse, and the junction between rod inner and outer segments. Rab8 was present in the inner segment of rods before they had fully developed outer segments. The localization of canine and *Xenopus* wild type GFP-Rab8 fusion proteins appeared to be identical.

DISCUSSION

The function of Rab proteins, members of the Ras superfamily of GTP-binding proteins, is intricately linked with their structure. The C-terminal region of Rab proteins contains a geranylgeranyl lipid group (Moyer and Balch, 2001), a hydrophobic region that can associate with membranes. When bound to GDP, however, Rab proteins cannot bind membranes because of conformational changes that tuck the geranylgeranyl group into the interior of the molecule (Papermaster, 2002). This allows Rab proteins to regulate membrane trafficking; GTP-bound Rab proteins can bind and transport vesicles, while GDP-bound Rab proteins are free to move throughout the cytosol and recycle to their original location (Moyer and Balch, 2001).

A correlation between Rab8 and polarized membrane transport was first made by Peränen et al. (1996), who showed that the expression of mutant canine Rab8 proteins in tissue cultures of MDCK cells and hippocampal neurons interfered with membrane trafficking in these cells. One of the mutant forms, Rab8-T22N, was a dominant negative mutant that locked Rab8 in its inactive state. The other, Rab8-Q67L, was a constitutively active mutant that locked Rab8 in its GTP-bound state. These two mutant forms of canine Rab8 were then expressed in transgenic *Xenopus laevis* rods by Moritz et al. (2001) to determine their effect *in vivo*. This work demonstrated that the expression of mutant canine GFP-Rab8 fusion proteins induced rapid apoptosis (programmed cell death) of transgenic *Xenopus*

photoreceptor cells. Although the *rab8* sequence is highly conserved among species, an analysis of the *Xenopus rab8* cDNA obtained by RT-PCR from retinal mRNA showed that there are 10 amino acid differences between the canine and *Xenopus* proteins. Nine out of the 10 changes are conservative and thus were not expected to affect the function or localization of the protein, but one is a non-conservative change; the nonpolar, hydrophobic proline present in canine Rab8 is replaced by a polar, hydrophilic glutamine in *Xenopus* Rab8. These subtle but potentially significant changes could affect the function of the protein. To determine whether the observed apoptosis of rod cells was caused by species differences or the introduced mutation, this study compared the expression of wild type and mutant canine Rab8 proteins with wild type and mutant *Xenopus* Rab8 proteins in transgenic *Xenopus* retinas.

Confocal images of transgenic tadpole retinas revealed that all Rab8 proteins were present in rod inner segments but not in rod outer segments. This finding is consistent with previous work on Rab8 (Moritz et al., 2001), and implies that Rab8 is involved in the transport of rhodopsin *within* the inner segment but is not involved in the transport of rhodopsin across the connecting cilium to the outer segment. As indicated by the areas of brighter fluorescence, there were higher levels of expression of GFP-Rab8 fusion proteins at three specific regions within the inner segment: the Golgi apparatus, the synapse, and the periciliary ridge complex (PRC), a region of membranous grooves at the base of the connecting cilium in amphibians (Peters et al., 1983). However, expression levels of the fusion proteins are partially dependent on the site of integration of the transgene within the genome and may not be indicative of endogenous Rab8 expression levels. The presence of Rab8 at the Golgi apparatus is consistent with previous work (Moritz et al., 2001) and suggests that Rab8 associates with vesicles as they are being sorted to their target membranes. It has also been shown that expression of mutant canine Rab8-T22N causes an accumulation of rhodopsin-bearing vesicles below the PRC (Moritz et al., 2001), suggesting that the fusion of vesicles, but not their transport, is inhibited by the mutant Rab8 protein. The localization of *Xenopus* and canine Rab8-wt throughout the entire rod inner segment is consistent with these data; it is not likely that Rab8 provides the signal for the polarized transport of rhodopsin because the localization of Rab8 is not polarized. It is the C-terminus of rhodopsin that probably provides this targeting signal (Tam et al., 2000).

The expression of mutant Rab8 proteins caused photoreceptor cell death. Rapid retinal degeneration occurred in transgenic frogs expressing GFP-*xrab8*-T22N and GFP-*crab8*-T22N fusion proteins. Because Rab8-T22N is a dominant negative mutant, its effects were apparent even in the presence of functional, endogenous Rab8. One possible explanation that could account for the dominant nature of the mutant is that transgenic mutant Rab8 associated with Rab-interacting factors (such as GDI and GEF), and thus acted as a competitive inhibitor of endogenous Rab8. Another possibility is that the expression of *rab8* transgenes in *Xenopus* downregulated the expression of endogenous *rab8* (as has been previously shown by Moritz et al., 2001) to a point where it could no longer sustain rod survival. Confocal images of the retinas expressing *rab8*-T22N indicate that all central rods died (based on the lack of red stain that labels rods), but peripheral rods survived. This is consistent with previous experiments using canine Rab8 (Moritz et al., 2001), and most likely occurs because peripheral rods are added as the retina grows, and thus did not express Rab8-T22N as long as the central rods. The few surviving central rods that express GFP-Rab8-T22N suggest that photoreceptor cell death in this system may be dependent upon expression levels of the transgene.

This study showed that Rab8 also localizes to the synapse of rod photoreceptor cells, and suggests that Rab8 may also play a role at this

location. Although the presence of Rab8 in the Golgi and post-Golgi pathways of vesicular transport is well documented (Peränen et al., 1996; Deretic, 1997), its role at the synapse, if any, has not been investigated. However, based on the fact that some Rab proteins have been shown to interact with synaptic vesicles (Pfeffer, 1995), it is possible that Rab8 is also involved in synaptic vesicle trafficking in rod cells. Because Rab8 was found primarily in two different regions within rod inner segments, the cell death caused by the expression of *rab8*-T22N-GFP fusion proteins may have been a result of interference of events in either or both of these regions. Further experiments are needed to determine whether mutant *rab8* causes rod cell death by blocking the transport of rhodopsin at the connecting cilium, or by blocking the release of synaptic signaling molecules that are responsible for initiating nerve impulses.

The mechanisms of photoreceptor cells are incredibly complex. As the results of this experiment demonstrate, even a single amino acid substitution in one Rab membrane trafficking protein can disrupt biochemical pathways and induce retinal degeneration. Previous experiments have shown that rod-specific mutations can also induce cone death in the retina (Dryja and Berson, 1995; Papermaster, 2002). Thus, in addition to providing insight into photoreceptor mechanisms in rod cells, *rab8* mutations may also be of value in obtaining a thorough understanding of the interactions between rod and cone photoreceptors. Although it is known that loss of vision is caused by the death of the rod and cone photoreceptor cells in the retina, it is unclear what causes the cells to die. Because the retina of frogs contains approximately the same proportion of rods and cones and is similar in structure to the human retina, this experiment provides an excellent model of human blindness. These studies are particularly relevant to macular degeneration, a devastating blinding disorder that affects over 25 million people worldwide. Furthermore, since *rab8* mutations reproducibly induce rod cell death in frogs, this system provides an inexpensive, rapid, and convenient assay to test potential therapeutic drugs designed to prevent rod cell death.

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Cellular Chaos: Reproducing the Results of Chaos Theory in Cellular Automata

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Abstract

In response to the current difficulties of using traditional math to describe complex systems, new representations have been formulated in an attempt to simplify these complex phenomena, such as chaos theory and cellular automata. Predictable and chaotic growth are properties of both the logistics equations in chaos theory and single-dimensional cellular automata. While this fact suggests a similarity between these two fields, no clear relation has been put forth. Our research shows that it is possible to model the behavior of chaos theory using cellular automata. This is demonstrated through the use of a variant of cellular automata, mobile automata, and its known relation to Turing Machines.

1. Introduction

A person stands up straight, and yet the human body does not stand perfectly still. It sways in a slight direction, corrects itself, and perhaps overcompensates, creating another imperfection in its balance. However, the motion is neither periodic nor symmetric. If the human equilibrium were managed in a random fashion, little correlation would show from one movement to the next. Although the motion does show a general repetitiveness in its back and forth movement, it is almost as if the human equilibrium operates with a degree of noise that prevents each movement from exactly repeating itself. Some may argue that such behavior may be the result of the complex thought processes of the human mind. This complexity, or perhaps the large number of concurrent bodily processes, may be argued as the reason why such a calculation may be impossible—simply too many variables to consider.

Although this problem remains moot, new approaches to the study of complex systems have successfully modeled systems with similar properties. These include the Red Spot phenomenon on Jupiter, the aperiodic dangling of a pendulum (Gleick 52-53), and the self-organization of snowflakes (Wolfram 370). Chaos theory and cellular automata, two such approaches for modeling complexity, have shown similar results for both predictable and apparently random growth. This is clearly demonstrated by the behavior of the logistics equations of chaos theory and single-dimensional cellular automata. Although this suggests a connection between the two models, no such model has been formulated.

Increased knowledge of these models and their relationship may illuminate their capabilities and limitations. Therein we may better understand the complexity of nature that they attempt to model. In addition, this may allow us to classify some phenomena as capable of being modeled by an individual field or several. Our research shows that it is possible to reproduce the results of mathematical chaos using a form of cellular automata, mobile automata. This paper discusses four similar themes that arise in these two fields, and then establishes their relationship through the use of Turing Machines.

2. CHAOS THEORY

2.1 Introduction

Chaos theory deals with the mathematics and behavior of the phenomena known as *chaos*. A misnomer, the term chaos does not refer to complete disorder, but instead to complex and in some cases apparently random behavior that is exhibited by some well-defined, deterministic systems. This behavior is often present in deterministic, nonlinear, and dynamic systems, some of which appear extremely simple (Williams 9). An important characteristic of chaos theory is "sensitive dependence on initial conditions." Many phenomena exhibit drastically different behavior when the input is varied from one value to another, even though the variation is minute. This responsiveness to the input makes them incredibly difficult to model using traditional methods. The mixing of milk and coffee exemplifies such behavior. When milk is poured into a cup of coffee, the milk often swirls around in two loops, one on each side of the point of contact. However, when this point of contact is changed, these loops rarely repeat themselves in size and shape, making them very difficult to model mathematically. Further, their behavior may change radically with a change in the point of contact. First, they may swirl in two loops, as said, but a small change in the initial conditions may result in a completely different pattern—such as a large loop on only one side. This difficulty remained until one mathematician decided to factor chaos into his equations (Dessart).

A compiler is another example of a system that demonstrates sensitivity to initial conditions. A program must be syntactically correct for a compiler to complete the compilation process. A small imperfection in syntax, such as the lack of a needed semicolon or bracket, will cause the compilation to fail and generate an error message. A single syntactical error may even cause 30 invalid error messages to be generated as a result of throwing the parser off track. Panic-mode recovery attempts to prevent the compiler from such misdirection, but the process is not perfect, and the above-mentioned behavior often still arises.

2.2 Discrete Logistic Equations

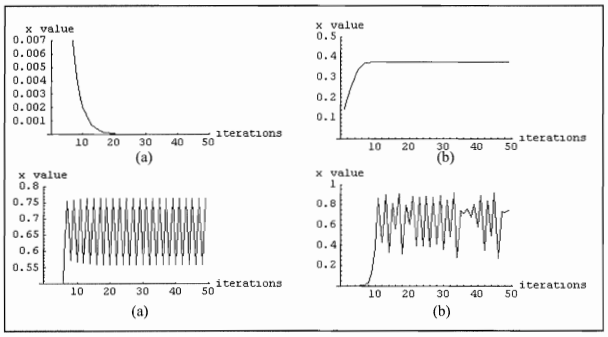
The exponential function, a rough population model, uses x_t to represent a population at a given time t, and a constant r to represent the change in population over a time interval. However, this equation, $x_{t+1} = r\,x_t$, does not allow for fluctuation in the population and places no limitation on population growth, which is unrealistic. In such a model, a growth rate greater than 1 will always result in massive overpopulation, and a growth rate less than 1 will eventually die out (Williams 161).

The discrete logistic equations make an improvement on the exponential function by multiplying the above equation by $(1 - x)$, allowing the population to fluctuate as well as rise and fall steadily. In this equation $x_{t+1} = r\,x_t, (1 - x)$, x is restricted to the interval [0,1] and represents the population as a percentage of the maximum possible population. The constant growth rate r is restricted to the interval [0,4] (Weisstein).

The logistic equations are often studied under iteration such that the function's output becomes the next computation's input. Formally, an iteration is expressed as $x_{t+1} = f(x_t)$ over some interval $[t_o, t_n]$ (Devaney 10-11). Given a starting point of $x_0 = 0.545$ with $r = 0.7$, $f_1(x)$ is computed to be 0.173582 (rounded). In the next iteration, x now equals the previous iteration's output, in which case we compute $f_2(x) = r\,(0.173582)(1 - 0.173582)$. Dependent on the value of r, iteration of the logistic equations shows one of four behaviors. The previous calculation with $r = 0.7$ shows the first of these behaviors, which is exhibited when $0 < r = 1$ (Williams 169). In this case, the value of x decreases as it is iterated. Further iteration shows that its orbit, or its value over a series of iterations, appears to approach 0 (Devaney 13). Thus 0 is called a fixed point attractor for the given function (Devaney 45). In fact, 0 is an attractor for any valid starting point, or seed, of x when $0 < r = 1$ (Williams 165). This can be graphed with the

values of x plotted against the number of iterations. Such a graph is called an iterated map, as portrayed in Figure 1(a) (Williams 163).

Fig. 1. Iterated maps of the four possible outcomes of the logistics equations, dependent on the value of r. These demonstrate, in order, the four possible outcomes: approaching 0 ($r = 0.7$), tending to a fixed value ($r = 2.95$), cycling ($r = 3.1$), and apparent randomness ($r = 3.675$), respectively in (a), (b), (c), and (d).



When $1 < r < 3$, the logistic equations are similarly attracted to a fixed value. However, this value increases as the parameter r increases. Thus when $r = 1.6$, x is attracted to 0.375 (Figure 1(b)); when $r = 2.4$, x is attracted to 0.58333; when $r = 2.95$, x is attracted to 0.661017 (Williams 169).

The third behavior is much more complex. When $3 = r < 3.57$ (approx.), a phenomena known as period-doubling bifurcation occurs. When r is close to the value 3, the orbit approaches and then settles down not to one value, but two. It continues to cycle between these values as the number of iterations increases to infinity, as seen in Figure 1(c). As r continues to increase, the value of x then cycles between four values, eight values, 16, and so on (Williams 167-168). The last interval demonstrates chaotic behavior. Since period-doubling bifurcation marks the transition between order and chaos, it is classified as a *route to chaos*. Other routes to chaos include intermittency and quasiperiodicity (Williams 189). As r increases above 3.57, the function exhibits chaotic behavior in which there is neither trend nor pattern, which continues beyond the number of iterations shown in Figure 1(d) (Williams 169). The behavior of the logistics equation can be summarized in a bifurcation graph. In such a graph, r is plotted on the x-axis, and the fixed-point attractors are graphed on the y-axis along their corresponding r-value (Williams 190-191).

2.3 Summary

Chaos theory is the study of complex and apparently random phenomena. *Chaos* is the term used to denote such behavior, in contrast to a complete lack of order. Some systems studied under chaos theory have been shown to produce drastically different results from only a slight change in input, which has led chaos theory to be called 'sensitive dependence on initial conditions.'

Discrete logistics equations, originally a population model, have been studied intensively under chaos theory. All behavior when $r = 1$ is predictable; all starting points tend to 0. As r increases, while remaining less than 3, the output approaches a fixed value between 0 and 1 that increases with the magnitude of r. As r increases over the interval above 3.0, but less than the approximate value 3.57, iteration cycles between an increasing number of values that are powers of 2. Iteration produces an apparently random sequence of numbers for each different value of r, when (approx.) $3.57 < r < 4$.

3. CELLULAR AUTOMATA

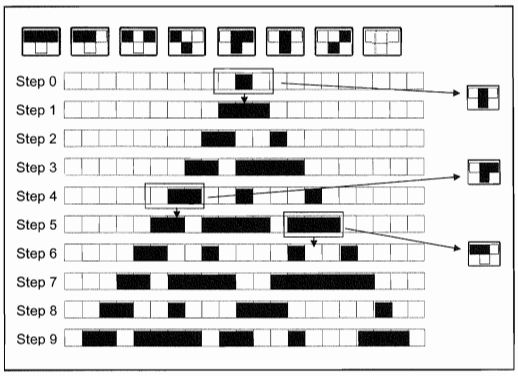
3.1 Introduction

Traditionally, science had maintained a strict dichotomy between simplicity and complexity: simplicity in the initial conditions yielded relatively simple results, while complexity yielded complexity. Conversely, simple computer experiments were shown to produce complex results, showing that very simple conditions were able to give rise to complex and even apparently random results. These results, shared by other approaches to model complexity, marked the resurgence of a field called cellular automata—the study of the behavior of a set of cells when growth rules are applied in iteration (Wolfram 1-3). A popular development of this field is John Conway's *Game of Life*, a form of two-dimensional cellular automata.

3.2 Simple one-dimensional cellular automata

This simple experiment involved the creation of one-dimensional cellular automata. One-dimensional cellular automata are represented by a horizontal row of cells. Each cell has a state, which is represented in black or white, and the row of cells as a whole represents the state of the system at a given time. The first row of Figure 2 demonstrates the initial state at a certain time in the system (Wolfram 24).

Fig. 2. Automaton created using Rule 30. The growth rule is shown above the figure.

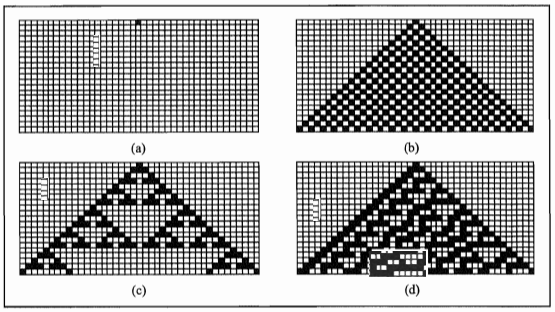


A growth rule is used to describe the next state of a cell after a given time interval. In simple one-dimensional automata, the next state of each cell is determined by its current state and the state of its two immediate neighbors. The top row of the growth rule, shown in Figure 2 above the automaton, represents a cell and its two neighbors; all eight possible combinations are described in the growth rule. The state of the cell in the next step is determined by this configuration and represented visually below the first row. The result, or next state, is typically presented underneath the current state (Wolfram 24).

Three cells, the state of itself and two immediate neighbors, determine the next state, which may be black or white. This allows for 256 possible combinations for growth rules. The three cells of the current state are always listed in the same order in the growth rule, and the value of the next state determines the numbering of the growth rule: black as the number 1 in binary and white as 0. Thus, the growth rule in Figure 2 is enumerated as Rule 30 (00011110 in binary) (Wolfram 53). The growth rule is initially applied to a given state; in Figure 2, this initial condition is a single black cell. The result is shown vertically below the initial state. In addition, three groups of cells are highlighted to demonstrate how the growth rule is applied. The corresponding portion of the growth rule is shown on the right (Wolfram 24).

A number of variations exist of this cellular automaton. Yet regardless of the type of automaton and the number of allowable states, only four themes arise. These themes include obtaining a definite size that repeats forever, a repetitive yet growing form, those with nested structures and fractals, and those with apparently random components. All four can be demonstrated using one-dimensional cellular automata. Figures 3(a), (b), (c), and (d) serve as examples of these behaviors (Wolfram 62-63).

Fig. 3. Automata created using Rule 2, Rule 122, Rule 22, and Rule 30, in (a), (b), (c), and (d), respectively. These serve as examples of the only four possible themes that result in all of cellular automata: repetitive fixed size, repetitive growing form, nested or fractal patterns, and apparently random features.



3.3 Summary

Cellular automata have shown that incredibly simple computer programs, such as the machine representation just discussed, have been able to create very complex results. In one-dimensional cellular automata, a horizontal row of cells represents the current state of the system. Each cell may be in one of two states, which are represented visually as black or white. A growth rule determines the next state of the system. In the growth rule, the current state of the given cell in

conjunction with its two immediate neighbors determines the next state of that cell. This is applied to all cells in the current state to produce the next state, and this process may be repeated a given number of times.

4. RELATIONSHIP: CHAOS THEORY AND CELLULAR AUTOMATA

4.1 Introduction

Despite fundamental differences in modeling complexity, the results of chaos theory and cellular automata each produce a total of four themes, as demonstrated using the logistics equations in Section 2.2 and one-dimensional cellular automata in Section 3.2. Section 4.2 elaborates on their commonalities. These four themes can summarize the themes of all possible results of these two approaches. However, the simple cellular automata that have been studied thus far appear to lack the continuousness of chaos theory. This claim, which proves not to be true, is discussed in Section 4.3.

The similarities in theme and continuousness show that cellular automata are comparable in computational ability to the models of chaos theory. In fact, through the use of Turing Machines, this paper will demonstrate that cellular automata are capable of computing mathematical equations and thereby capable of reproducing chaos theory. Turing Machines are introduced in Section 4.4, and they are applied to the discussion in 4.5.

4.2 Four themes

Studies examining a wealth of results from both fields have shown that only four possible themes may arise in chaos theory and only four in cellular automata, despite differences in modeling complexity. These themes have been demonstrated using the logistics equations in Section 2.2 and one-dimensional cellular automata in Section 3.2. These themes arise in similar, yet slightly different manners for the two fields. The resulting theme always depends upon the next state function—the mathematical function in chaos theory and the growth rule in cellular automata. The resulting theme of a cellular automaton, however, is also dependent on the initial condition. Thus, different initial states of a single growth rule may result in different themes, in contrast to chaos theory.

The arising themes also show great similarity. The first two in both fields show a degree of order through repetition. The latter themes show increasing complexity through self-organization and apparent randomness. The first shared theme is attraction to a fixed value or state. Many orbits of iterated functions are attracted to and reach a fixed value, in which all subsequent iteration yields the same value. Similarly, many cellular automata are attracted to one fixed state, in which further application of the growth rule produces that same state. Figure 3(a), for example, is immediately attracted to a state of all white, such that further computation yields only this same result.

In chaos theory, it should be noted that some orbits are asymptotic to the values to which they are attracted. This occurs in the logistics equations when $r < 1$, in which the orbit is asymptotic to its attractor, zero. Similar behavior does not seem to appear in simple cellular automata, but this most likely results from its discrete nature. Asymptotic behavior may be demonstrated by continuous cellular automata.

The second theme has the property of approaching a fixed pattern. In chaos theory, the orbit of a function may approach, or take several computations to settle down, to a cycle. It should be noted that functions do not only cycle during bifurcation, although this is the interval in which the logistics equations do. Correspondingly, cellular automata may approach a fixed state, infinite in size. Figure 3(b), for example, continues to grow, yet in a very repetitive pattern, thus, approaching a state of this pattern that extends infinitely in width. Figure 3(b) demonstrates this behavior by approaching a fixed, checkered state of infinite width.

The third common property is self-organization or fractal patterns. A cellular

automaton that shows a fractal pattern, or self-similarity under magnification, is Figure 3(c). The bifurcation graph of the logistics equations demonstrates the self-organization of the logistics equations. Magnification of an interval of this graph (not shown here), in example [3.44, 3.58], would show the self-similarity to the larger whole of the bifurcation graph.

The fourth theme shows the property of apparent randomness. The logistics equations generate apparently random sequences of numbers when $r > 3.57$ (approx.). One such sequence is graphed in Figure 1(d). The apparent randomness of cellular automata is demonstrated in the states of the center column of Figure 3(d). In fact, the sequence generated by the values of the center column has passed all current statistical tests for randomness (Wolfram 1085).

4.3 Structural continuity in approaches

A continuous form of the logistics equations does exist although it has not yet been mentioned in this paper. In this form, the value of x may be examined at any point in time, which is computable through the use of differential equations. Thus, t is not limited to discrete values such as 1, 2, or 3; t may equal fractional values such as 1.3. Simple cellular automata lack this continuity. The number of steps computed is always discrete; one-and-a-half steps cannot be computed. In addition, the environment is limited in a discrete manner; between any two cells in a given state, there are a discrete number of cells. However, cellular automata can use partial differential equations to define the state of every infinitesimal point in time and space, thus eliminating all inherent discreteness. Since the use of partial differential equations requires more mathematical computation and creates a more complex visual representation, simple, discrete cellular automata are more commonly studied (Wolfram 161).

Second, the state of a cell in simple cellular automata is limited to two possible values. Again, cellular automata can easily accommodate this distinction. By using three or more values, such as 0, 1, and 2, or even a closed interval, such as [0,1], the state of a cell then allows for the continuity attributed to the logistics equations. These are often portrayed visually using colors or shades of gray (Wolfram 155-156).

4.4 Turing Machines

The Turing Machine was one of the first developments in theoretical computing. Created by Alan M. Turing, the Turing Machine was designed to assist programmers and theorists in distinguishing what is achievable through programming from what is 'undecidable' (via Hopcroft 316-317). The Turing Machine is in fact a gross simplification of a computer. The machine consists of a long tape and a control head. The tape is divided into cells that distinguish one data address from another, and the head is capable of writing symbols from the input alphabet onto the tape and moving from one address to another. A transition function maps how the head will respond to a given input, which may depend on the current state of the cell (via Hopcroft 318-319).

Since most devices on a computer can be broken down into processing, storage, and input devices, the tape head, tape, and set of input symbols equate to a simplified computer rather well. The Turing Machine can read and write values to the tape and use the stored values for further computation. The tape may act as a multipurpose storage device: hard drive, removable disk, memory, etc., which alleviate the overhead required for multiple device interaction (via Hopcroft 359).

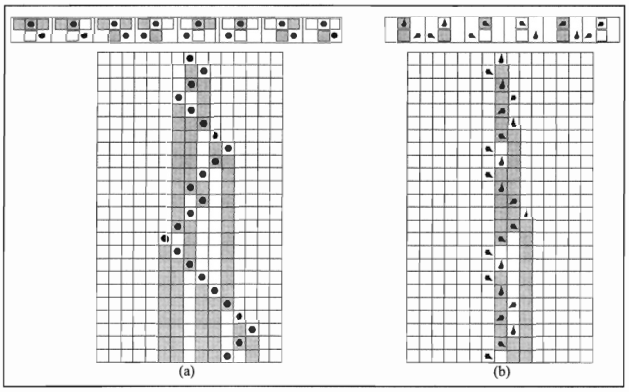
The claim that Turing Machines are equivalent in computational ability to the intuitive notion of computation and various other models, including mathematical functions, is derived from the Church-Turing thesis,[1] which states that all computations are defined by algorithms. If one can write an effective, finite, clearly defined, and unambiguous algorithm, it is computable. However, the informal notion of computation cannot be mathematically represented. Thus, this thesis remains unprovable by mathematics (via Hopcroft 318).

4.5 Reproducing the results of chaos theory in cellular automata

It is known, by means of the Church-Turing thesis, that the Turing Machine can compute any mathematical function. Hereby, the Turing Machine can compute the discrete logistics equations for some value of *r*. In fact, a series of Turing Machines can compute the logistics equations for all values of *r* (via Hopcroft 318).

In addition, Stephen Wolfram has documented that a variant of cellular automata, mobile automata, can compute the functionality of a series of Turing Machines (Wolfram 78). The main distinction between mobile automata and simple cellular automata is that only one cell of the former is updated per step. In Figure 4(a), this active cell is marked by a dot, and the growth rule is shown above the automaton (Wolfram 71).

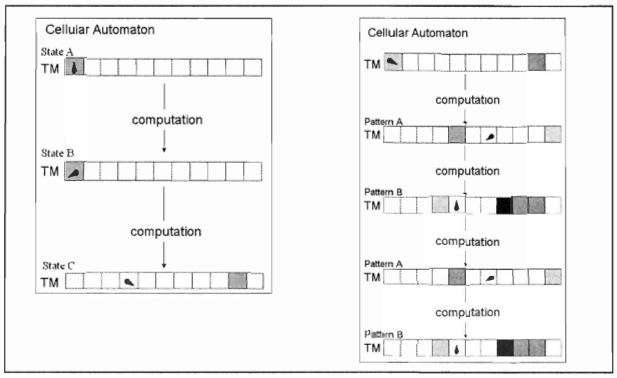
Fig. 4. Mobile automaton (a) and Turing Machine computed in a mobile automaton (b).



In order to function as a Turing Machine, the active cell must serve as the tape head. This requires the state of the head to be included in the automaton; in Figure 4(b), this is represented as an arrow, and its direction (up, left, or right) identifies its current state. The state of the control head also must be factored into the growth rule, which is shown above Figure 4(b) (Wolfram 78). Since a modified mobile automaton can function as a series of Turing Machines, and a Turing Machine can compute all mathematical functions, hypothetical syllogism shows that this variant of cellular automata can compute all mathematical functions. Some mathematical functions contain chaos; thus, this variant of cellular automata can compute all mathematical chaos.

Figure 5(a) presents a general simulation of a cellular automaton computing a mathematical function. The initial state of the cellular automaton denotes the seed for the mathematical computation. This is denoted as State A. The automaton proceeds to compute a mathematical function. During the computation, the head moves around, changing state, and changing the values of cells. State B shows the state of the automaton when some computation but not all has been executed. The values of the cells in State C represent the output value of the automaton. The states in between A, B, and C have been omitted to show how the automaton can compute a function from an initial state and end, outputting the result.

Fig. 5. Encapsulation of a Turing Machine in a cellular automaton (a). Encapsulation demonstrating cycling (b).



Further to show how a cellular automaton can reproduce the behavior of mathematical functions, Figure 5(b) simulates a cellular automaton computing a function that cycles between two values. The initial state of the automaton represents the seed for the computation. The automaton produces a Pattern A in the second state shown. Further computation produces Pattern B, then Pattern A, then Pattern B again, cycling back and forth between these two states. This pattern becomes apparent only when the underlying computation is omitted.

5. Conclusion

This paper has shown that cellular automata are fully capable of reproducing the results of chaos theory through the use of the Church-Turing thesis and a variant of cellular automata. From the Church-Turing thesis, it is conjectured and well accepted that Turing Machines are able to compute every effective algorithm and computation. In addition, a variant of cellular automata, mobile automata, are able fully to model the Turing Machine with only a slight modification. By hypothetical syllogism, cellular automata are capable of computing all mathematical functions, both chaotic and non-chaotic.

All of chaos theory can now be reproduced using cellular automata. These new models offered by cellular automata may shed some light on subjects previously studied under chaos theory. This does not, however, mean that cellular automata will always be preferable to chaos theory. It is likely that many phenomena will remain more appropriate for chaos theory because of its continuous and easily quantifiable nature. In addition, these conclusions provide us with more information about the models used to study complexity. By better understanding these models of complexity, we will gain in understanding the complexity we find in our universe—the complexity that we attempt to model.

It should be noted that nothing has been said about reproducing the results of cellular automata using chaos theory. This has been deliberate because this subject merits its own discussion. Cellular automata are based on mapping values to new values, which mathematics is capable of. Although this may take place in a variety of dimensions in cellular automata, I speculate that this may be possible. The underlying calculations, however, may require very complicated matrices and other mathematical artifacts.

6. Acknowledgement

I would like to thank Professor Nobo Komagata, my research mentor, for guidance and input that helped make this paper possible.

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Appendix

i Strictly speaking, the collection of mathematical functions that are computable as partial recursive functions.

Proportional Control of NiTi Shape Memory Alloy

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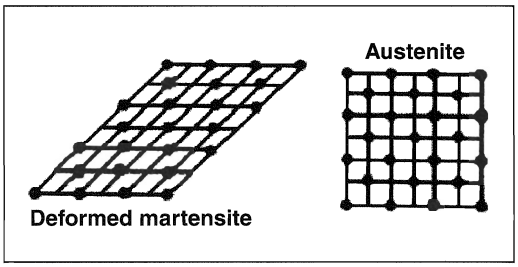
Abstract

Nickel titanium alloy wires have the ability to contract and shorten their length when the material has been heated above a specific temperature. This contraction will exert force on any mechanical linkage that the wire is fixed to. The objective of this research is effectively to control the contraction process of the wire by controlling the contraction percentage and speed. This would be very desirable as the wires exhibit a high power/weight ratio, and easily are able to perform motions that are difficult for other motivation devices. To achieve this goal, the transformation process of NiTi alloy wires has been investigated and a control algorithm has been devised that will allow the NiTi wires to halt transformation mid-contraction, which is desirable for many applications, such as robotic manipulators and prosthetic limbs. The control algorithm has been applied to a walking robot, which successfully demonstrates the concept of using NiTi wires to control the movement of robotic limbs. This demonstrates the feasibility of a lightweight, self-contained robotic manipulator with greater accuracy and control than what is available to the public now.

1. Introduction

The Naval Ordinance Laboratories discovered nickel titanium alloy in the early 1960s to have many interesting and intriguing properties. It was found that the material exhibits the ability to contract and stiffen when its temperature was raised above a certain level. It was also found that the alloy exhibits a shape-memory effect, in which the material is flexible when at room temperature, but will assume a predefined shape when the heat threshold is surpassed. For this reason, NiTi is called a Shape Memory Alloy. These effects have since been studied and have been found to occur because of a reversible solid-state phase transformation that takes place dependent on temperature at the molecular level. The molecules of the material can assume two geometric shapes, depending on whether they are in the martensite or austenite phase. The martensite phase is the cooled state in which the crystals take an elongated form, which allows the material to be easily deformed. The austenite phase is the heated phase in which the crystals assume a more ridged, cubic form. This behavior is noticeable in Figure 1.

Figure 1. This depicts the geometric difference between the relaxed martensite phase and the contracted austenite phase.



One major benefit of this transformation is that the material will contract with a relatively high degree of speed and force, about 22,000 pounds per square inch contracting 5-20% in length in approximately one second. The material can also exist in a super-elastic

state, which occurs when the alloy is in mid-transformation. The contraction property (as well as the super-elasticity) is the basis for this experiment.

Currently in industry, the material has been utilized for its super-elastic properties as well as its contraction properties. The super-elastic property has been used in modern dentistry, as the alloy mixed at the proper level will remain in its super-elastic state at the temperature of the body, which allows the wire to behave like strong rubber bands for use in orthodontics. The flexibility of the material has also led to its use in the medical field as a catheter for large veins and arteries. Thanks to the high contraction power/weight ratio, NiTi has also found applications in space as actuators for sensors. The principle for actuation is that a wire undergoes transformation through ohmic heating, which requires that an electric current pass through the wire. This allows the contraction of the wire to be electrically controlled by a computer through the application of current. As a result of their contraction property, NiTi wires have been nicknamed muscle wires. When heating the wire, the amount of current in relation to the cross-sectional area of the wire will determine how quickly the material contracts, since high current will heat the wire much more quickly than low current. When the current level is too low, the material will not undergo phase transformation and will remain in its martensite phase. The goal of this research is to attempt to apply NiTi as a means of proportional control of the deflection and speed of a robotic actuator by carefully controlling the current through an actuator and allowing the wire to halt phase transformation mid-contraction.

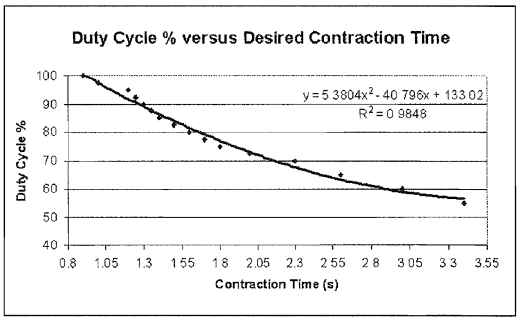
2. METHODS

2.1. Analysis of the behaviors of NiTi caused by ohmic heating

The initial focus of the research was accurately to determine the behavior of NiTi wire caused by ohmic heating. The amount of current passing through the test wire was controlled by varying the duty cycle of a pulse width modulated (PWM) signal that was applied to a field effect transistor (FET), which behaved like a switch turning off and on rapidly. The PWM signal was produced by a digital signal generator, which could control the duty cycle percentage within .1%. A highly accurate potentiometer with low turning friction was used to capture electronically the contraction of the wire in relation to time. The $^1/_2$ m wire was hung from a ring stand, looped around the knob of the potentiometer, and connected to a 100 g mass. This allowed the resistance of the potentiometer to change as the wire contracted and relaxed. The resistance was measured by a digital ohmmeter and logged through its data bus with a computer. The resistance of the potentiometer was then measured at various contraction lengths in order to determine the conversion from resistance to contraction.

To test the wire, the manufacturer's specification for maximum current allowed through the wire to maintain a high-lifespan (nearly 10 million cycles) was set as the current when the duty cycle was at 100%. From there the wire was allowed to contract at different duty cycle percentages, and the contraction was logged in the computer. The relaxation data also were recorded, which occurred as the wire cooled. The contraction data were compiled for a large range of duty percentages and the duty percentage versus average contraction time was plotted.

Figure 2. This shows how the full-scale contraction time increases as the duty cycle decreases. The equation representing this relationship is: Duty Cycle = $5.38^*T^2 - 40.796^*T + 133$



From this a second order polynomial equation was fitted to the plot as seen in Figure 2. This equation allows for the proper duty cycle calculation based on a desired contraction speed.

This experimental procedure found that below 40% duty cycle, the wire would not heat enough to initiate contraction. However, it was also noticed that the wire would not relax when the duty cycle was above 35%. This led to speculation that there might be an optimum duty percentage that would cause the wire to halt the transformation at any point in the contraction. This idea was tested by initiating contraction of the wire and switching the contraction percentage to 38%. It was found that the wire would indeed halt transformation, thus maintaining a mix of martensite and austenite phases throughout the material.

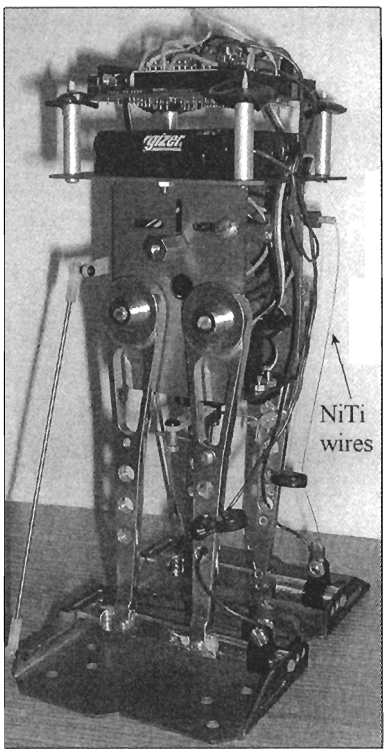
2.2 Controlling the wire

It was decided that a walking robot would be a perfect host for the wire actuators, as it would allow the wires to be connected in a manner similar to muscles. Muscle wire actuators could be an excellent fit for robotic and prosthetic manipulators because of their remarkably high power-to-weight ratio and high lifespan.

A preexisting walking robot that used servo motors as the method for motivation was used. It was decided that the NiTi wires would replace the servo that controlled the forward and backward motion of the legs. This would result in a great loss of weight for the robot, as the servo motor is quite heavy and the added weight of the NiTi wires is essentially negligible.

For control of the actions of the robot, including the NiTi wires, the robot included a BS2 Basic Stamp microcontroller made by Parallax. This microcontroller allows the upload of a program that can be easily edited on a computer and executed on the robot. The microcontroller was mated to a pulse width modulation board (PWMPal®, Parallax), which will allow the independent control of up to four different wires while allowing the main microcontroller to resume regular processes. The outputs from the PWM board were connected to the gate of JFET transistors, which would switch on and off the power from the batteries to the NiTi wires. The wires selected for the robot have a diameter of 0.006 inches (similar to a thick strand of hair) and can lift 330 grams with a high number of life cycles; the transition temperature of this particular NiTi mix was 90° C. They were attached to the front of the legs as shown in Figure 3.

Figure 3. This is a photograph of the robot. Notice the NiTi wires connected across the front of the leg. This leverage allows the wire to move the leg forward.



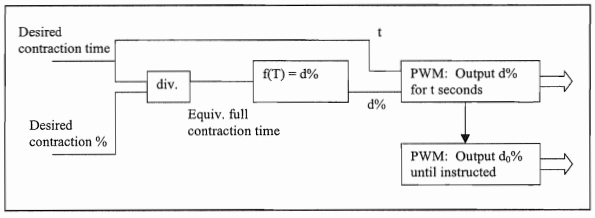
The two legs are mechanically linked, which allows only two wires to control the forward and reverse movement of both legs. It was decided to pair two 0.006″ diameter NiTi wires for each leg, which gives more power and reliability to the stroke of the legs. This method could be applied to match a mechanical actuator to any specified force requirement. A servo that controls the side-to-side

leaning of the robot was maintained, as the twisting of a servo matches that motion more effectively.

2.3 Programming the microcontroller

The equation defining full contraction time in relation to duty cycle percentage (d% = f(T)) was combined with the knowledge that at some duty cycle percentage (d_0%) the phase transformation will halt, which allowed a control algorithm to be created. Since at a known duty percentage (d%) the wire will undergo a full contraction in T seconds, it is reasonable to say that the wire will contract X percentage of a full contraction in X*T seconds. This means that if it is desired to contract the wire halfway at a rate of a given duty percentage, if that duty percentage is applied for $^1/_2$ f(d) seconds and then the halting duty percentage (d_0%) is applied, the wire will stop the wire mid-contraction and hold at that point indefinitely. An example of the control scheme is shown in Figure 4.

Figure 4. This illustrates the control algorithm, which allows the wire to contract to a desired percentage of the full length in a desired amount of time. The PWM chip will output the halting duty cycle d_0% after t seconds, which will hold the actuator in place until further instructions are given.



The microcontroller was programmed to walk by constructing subprograms that execute a specific motion, such as leaning and taking a step. By executing all of these subprograms in the correct order, the robot was made to walk six steps and then stop, standing upright. By changing the duty cycle percentage, the robot could be made to walk at different paces. When the proportional control algorithm was implemented, the robot could walk while controlling both the stride length and the contraction speed. A more dramatic demonstration was designed by programming the robot to extend a leg forward and hold it a one-half full extension for 15 seconds, and then the robot extended the leg fully, took a step, and stood upright. This demonstration proved that NiTi wire actuators are usable for proportional control when they are controlled properly.

3. Results and Discussion

The demonstrations of the robot's abilities confirmed the idea that NiTi wires could be used effectively to control numerous forms of actuators in all ranges of size and force. The basic control principles used can be applied to applications requiring more force by simply increasing the number and thickness of the wires. For a more effective application, feedback is essential, as it will allow the microcontroller to calibrate the halting duty cycle percentage as environmental conditions change. This is similar to the human muscle control system, in the way that if a person was holding her arm out, and a weight was placed on it, she will have to compensate by instructing her muscles to exert more force to compensate for the added weight. As a robotic arm manipulates different weights the halting duty percentage d_0% would be modified constantly, just as the human brain does. What makes the idea of NiTi actuators so desirable is that they are extremely light and can easily achieve motions that are very difficult to accomplish with other mechanical methods of motivation. This can allow for prosthetic devices, such as hands, which could have the full range of motion of a normal hand and would look the same since the mechanical construction could be modeled after the human hand. As the field of neuroscience advances toward interaction with nerves, it is conceivable to have a prosthetic device that can replace an appendage while allowing the brain to control each muscle wire in the same manner as a real muscle. NiTi is also well suited for this application thanks to its high resistance to corrosion, which is why it is currently used in the medical industry.

Another application of the NiTi actuator could be micro-devices. Since the contraction

is calculated by percentage of the wire length, the same control principles could apply to wires of any length. The only major disadvantage of using NiTi wires is that the amount of power needed to heat the wire is greater than that of other means of motion. The wires used in this experiment require 400 mA of current at 100% duty cycle, which is more than the 50 mA required by the servo it replaced. Yet, the weight loss is probably enough to compensate for this higher power requirement in most applications.

The goals of this research have been achieved, in that the principle of proportional control of NiTi wires has been applied and demonstrated. A goal of further research would be to investigate the application of feedback to maintain a higher degree of accuracy and adaptability, which could lead to industrial application of NiTi wires where control devices such as servos, solenoids, and pneumatics are currently utilized.

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[3] Toddler Walking Robot® and PWMPal®, available at www.Parallax.com.

Conference Proceedings

Listed below are abstracts of student-faculty collaborative work presented at regional, national, and international conferences.

Kerin Halper, Danielle McConnell, and Blythe Hinitz
The College of New Jersey
(Blythe Hinitz, Faculty Sponsor)
Valuing Infant and Toddler Play: Research Supporting "What Comes Naturally"

Presented at the Coalition of Infant/Toddler Educators [CITE] Conference, Cherry Hill, NJ, April 2, 2004

This workshop explored recent research on play and its relationship to daily activities in the infant and toddler classroom, focusing on two studies conducted in local childcare center classrooms. Handout and bibliography were provided.

Throughout the spring 2004 semester, Kerin Halper and Danielle McConnell conducted research at the Merrill Lynch Day Care Center in infant classrooms. They hypothesized that children learn more independence from adults through play at the center than they learn through play at home, and that culture plays an important part in adult interactions with infants during play. They began their presentation, along with Professor Hinitz, by acting four vignettes that could occur in an infant classroom. The group then was divided into four sections to discuss what happened in each of the vignettes. This was followed by a large group discussion. Professor Hinitz gave the group some information about theory, and then Kerin and Danielle presented their research material. They concluded by sharing information about communication.

Sara Beauchemin, Christine Day, Colleen Lacey, and Solveig Smith
The College of New Jersey
(Harlene Galen, Faculty Sponsor)
The Nursery School Movement: Its Relevance Today!

Presented at the annual conference of the New Jersey Association for the Education of Young Children, East Brunswick, NJ, October 18, 2003

The presentation used Howard Gardner's theory of multiple intelligences to create an interactive review of the significant contributions of prime movers in the nursery school movement. Emphasis was placed on influences made by people such as Maria Montessori, Caroline Pratt, and Arnold Lucius Gesell and their relevance to the way we teach students today. Each student used her different technique to relay her information to conference attendees. The presenters asked participants to use paper unit blocks to measure, compare lengths, and learn about fractions. Participants also learned about Maria Montessori's didactic materials by creating sandpaper letters for their students to use. The presenters also showed how music can help children express feelings and open their creativity through movement and dramatic play. The participants moved around the room to music while pretending to be different animals to match the instructions of a song. The presentation ended with an open discussion about parent involvement. The presenters offered some ideas and then opened the discussion to the audience and

participants shared what had worked for them and what had not.

Elizabeth McGlinchy, Alicia Roening, Melissa Poli, Leigh Garrett, Lisa Cipriano-Rigalski, Melanie Burd, and Blythe Hinitz
The College of New Jersey
(Blythe Hinitz, Faculty Sponor)
Native American Arts and Literature

Presented at the Delaware Valley Association for the Education of Young Children Conference, Philadelphia, PA, March 15, 2003

This two-part workshop enabled participants to develop activities and lessons that support young children in their constructive play and emergent literacy. Participants were involved in large group activities involving a Native American "talking stick," sign language, a "making the rain" dance, and a "Navajo Prayer." Participants were also involved in small group activities in which they could make sand art, ceremonial masks, totem poles, rain sticks, or Native American pouches. All these activities were developmentally appropriate for use by and with young children. At the conclusion of the workshop, participants were presented with handouts and a bibliography.

Molly McGoldrick and Rick Addante
The College of New Jersey
(Andrew Leynes, Faculty Sponsor)
Brain activation associated with semantic memory for gender stereotypes: An ERP study

Presented at the Council on Undergraduate Research Annual Posters on the Hill event Rayburn House of Representatives Building, Washington, D.C., April 22, 2004

A previous study from our lab indicated that gender stereotypes can be used to make source memory judgments (i.e., memory for the origin of information). This situation produced a pattern of activity that seemed to suggest that implicit stereotypes affected brain activity during the source memory test. The goal of the present study was to determine how brain activity is affected by semantic memory for gender-stereotypical words. The results of the study suggest that ERP activity during semantic retrieval is very similar to ERP activity during source judgments based on gender-stereotype information. Furthermore, the ERP data also suggest that implicit gender stereotypes affect brain activity in a similar way when semantic memory is tested.

Note: The Council on Undergraduate Research competitively selects two students per state to present their scientific research to senators, congressmen/women, and policy makers in Washington, D.C. every year, stressing the importance of supporting undergraduate research and scientific research in general.

Jane Marchetti
The College of New Jersey
(Lawrence McCauley, Faculty Sponsor)
The Playboy and the Riots: Donnybrook or Demiurgy?

Presented at the American Conference for Irish Studies, New England Chapter, Saint Anselm College, Manchester, NH, October 15-16, 2004

When, in 1907, J. M. Synge sent his central character in *The Playboy of the Western World,* Christy Mahon, out on the stage of the Abbey Theatre, "walking forward facing hog, dog, or divil," some would say that he produced a donnybrook (Harrington, 81). "As soon as the curtain was raised on *The Playboy,*" reported Dublin's *The Daily Express,* January 26, 1907, "it at once became evident that a large section of the audience were intent on expressing their disapprobation of the piece" (qtd. in Hogan and Kilroy 126). This disapprobation—literally a visceral aversion to the playwright's presentation of the Irish peasantry in the character of Mahon—took the form of "boohs, groans, and hisses" so loud that not even the arrival of six constables could quell the interruptions.

At the following night's performance, the *Express* reported "disturbances more remarkable than those of the previous night," which prompted Synge's fellow revivalist, William

Butler Yeats, to come out to address the audience: "A difference of opinion has arisen between the management of this theatre and some of the audience as to the value of the play which we are now to produce, and as to our policy in producing it. If any of you wish to discuss the merits of the play, or our rightness in producing it, I shall be delighted to discuss it with you" (qtd. in Hogan and Kilroy 127). And thus began a debate that continues today.

But this play and its early productions need not be cast as an author/audience opposition. My paper looks at what Mary King calls "the complex interactions of play, world and word," the meta-drama surrounding the play, to show how *The Playboy* can be seen as a creative force, as an attempt on the part of both author and audience to construct a new national identity in a not yet post-colonial Ireland (133).

Works Cited

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Ryan Fehr, Erin L. Byrnes, Lawrence A. Fehr, and John P. Galla
The College of New Jersey
(Jean Kirnan, Faculty Sponsor)

Elder Abuse: A Cross-Cultural Analysis

Presented at the National Social Science Association Professional Development Meeting, Baltimore, MD, October 13-15, 2004

This study was performed to investigate college students' perceptions of the physical abuse of the elderly. The sample comprised students enrolled in undergraduate day courses at Widener University in Chester, Pennsylvania, and La Università di Firenze in Florence, Italy. Each participant completed a demographic profile and responded to five questions pertaining to one of four different fictitious abuse cases, which were randomly assigned to the participants. The questions were designed by the researchers to determine if there is a difference in college students' perceptions of elder abuse. More specifically, the country-of-origin of the participant, the alleged victim's physical health, and the alleged perpetrator's level of depression were examined. Important findings include that Italian students judged the alleged crime as more serious than American students and that American students found greater perpetrator fault and likelihood of conviction than Italian students.