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Research Journal possible.*

The 2012-2013 Editorial Board is excited to present the 11th edition of the University of Texas at Austin's Undergraduate Research Journal. This edition of the journal is the product of a fantastic year of submissions. Not only did we succeed in almost tripling last year's number of submissions, but we also received an unprecedented amount of excellent articles in a broad range of areas. This year's edition is testament to that fact; included in this edition are articles about nuclear morphology, dynamic equations and 20th century literature. Although all articles appearing in the journal are of phenomenal quality, this year's winners of the first and second-place awards for best article are Travis Alexander and Emily Lantz, respectively.

The URJ has also made great strides in fulfilling our mission to promote undergraduate research on campus. In the fall, we hosted a research panel in conjunction with the Undergraduate Business Council in order to bring awareness to the importance of research in business careers. Our outreach efforts also resulted in the submission of research articles from schools and departments that recently started to encourage their students to complete research as part of their degree. Lastly, the Library of Congress has received copies of our journal, so all the articles of all published authors will now live permanently in the nation's capital.

It is important to mention that the journal has received an abundance of support from a variety of faculty and staff at UT. We especially thank the Office of the Vice President of Research, the Office of Student Affairs, the Senate of College Councils and the University Co-op for their exceedingly generous support this semester. We would also like to thank the Office of Undergraduate Research for their promotion of undergraduate research, as well as for their much-appreciated support of the URJ.

Sincerely,

Tim Smartt

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A New Mythology for the Space Age: William S. Burroughs and the Rejection of Linear Thought

*The University
of Texas
at Austin*

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Travis Alexander

In 1914, William Seward Burroughs was born into a life of affluence and security. The child of a wealthy Saint Louis family, the young Burroughs acquiesced to the bourgeois ambitions of his family and attended Harvard. He grew restless amid this milieu of pomp and erudition, however, and immediately after graduation, committed himself to a life of intellectual nomadism and narcotic mysticism that was to be his wont for the next sixty years. Along his travels through Mexico City, Morocco, and New York, Burroughs befriended future beatnik gurus Jack Kerouac and Allen Ginsburg—both of whom looked to the older hipster for cultural and literary inspiration. As

these relationships blossomed, they became interdependent; Ginsburg acted as Burroughs' de facto literary agent, hawking his first manuscript—*Junkie*—until it was published in 1953, and Kerouac—far gone in his own countercultural performance—later shepherded Burroughs through the emotional and chemical trials that surrounded the writing and publication of his magnum opus, *Naked Lunch* (a title suggested by Kerouac).

But in the cultivation of a lore as consuming as was Burroughs', many scientifically-oriented aspects of his writing have been eclipsed by the biographical impulse that structures, in part, the agenda of literary history. Though many readers are aware of Burroughs' *Naked Lunch*, and a subset of that group know Burroughs' "cut-up" technique—the shuffling of narrative segments into an atemporal nonsequential order—few scholars have interrogated the role played by this approach in installing Burroughs as a participant and contributor in the twentieth-century discourse on non-linear thought. From opium dens in Tangier and the "Beat Hotel" in Paris, Burroughs engaged with the intellectual upheavals otherwise attributed to Marcel Duchamp, Albert Einstein, J.W. Dunne, and P.D. Ouspensky. His refusal to clarify his own theories, though, exiled him from the collective intellectual consciousness, both American and Continental. Exposition of Burroughs' interviews and disclosures, however, reveals the sweeping contribution Burroughs made (or at least, aspired to make) to the dominant discourses of space-time, the fourth dimension, and the block universe theory—discourses whose allure in mystical and intellectual circles in the twentieth-century might, today, go unquestioned. In particular, Burroughs' intentions with the cut-up technique and his interpretation of dreams prove enlightening toward this end. They both attempt subversions of standard narrative order, and in so doing, subvert the very space-time logic upon which that order is predicated. In studying their use, we can discover the range of intellectual upheavals attempted by the figure some called *El Hombre Invisible*.

Under the Knife

We can cut wherever we want, I my reverie, you the manuscript, the reader his reading; for I do not bind the latter's recalcitrant will to the endless thread of a superfluous plot. [...] Chop it up into many fragments, and you will find that each one can exist separately.

- Charles Baudelaire¹

Among the most salient features of Burroughs' corpus from *Naked Lunch* onward is the jarring discontinuity between sequential sentences, paragraphs, and pages. Implicit in—and indeed, foundational to—this "cut-up" is the notion that words need not exist on a page in the linear order in which they were composed.² For example, the vignettes—

1 Oliver Harris and Ian MacFayden, *Naked Lunch @ 50 Anniversary Essays* (Carbondale: Southern Illinois University Press, 1999), 97.

Burroughs called them “routines”—that populate the novel’s conclusion rapidly, often incomprehensibly, cycle through both setting—Mexico, the US, the hallucinogenic “Interzone”—and modes of temporality: past and present. This choice served many functions for Burroughs—most rudimentarily, it embodied his idiosyncratic narrative impulse. And this idiosyncrasy arose precisely from its internal “logic” of disjunction: “[I write in] a very old tradition, namely, that of the picaresque novel,” Burroughs remarked in a 1974 interview. “People complain that my novels have no plot. Well, a picaresque novel has no plot. It is simply a series of incidents.”³ By 1974, this privileging of the non-linear narrative was cemented in Burroughs’ mind; his disdain for linearity is evidenced as early as 1957, when Ginsburg wrote to Burroughs advising him to arrange *Naked Lunch* linearly. Burroughs responded that he considered any attempt at chronological representation ill advised, as it would fail to render the novel’s attempted disavowal of temporal meanings.⁴ While a tradition of non-linear arrangement did exist in literature before Burroughs’, it had been confined, mostly, to the normative (indeed, *normalized*) confines of *in medias res*: beginning in the middle of things. But that tradition, as opposed to Burroughs’, ineluctably continued to forward the notion that there was a given order, an order which, for the time being—and the time being only—had been shifted. *In media res*, that is, attempted no subversion.

The cut-up clearly possessed a narrative appeal for Burroughs, but its real attraction lay in its suggestion of visual art and the implications of such an evocation: overlapping senses, acts of representational revolt, and general expansion of consciousness. Consciousness expansion, for Burroughs, meant both the willingness to abandon Aristotelian logic and the ability to question the very premises of the space-time continuum. Here, Burroughs took as his target the most basic configuration of Aristotelian, or “term” logic: that of the *proposition* composed of two *terms*, in which one term affirms or denies the other term; and at the larger level, the logic within which two propositions can establish the truth of a third, in the *sylllogism*. And so, it seems only fitting that Burroughs’ inspiration for the cut-up originated in his friend Brion Gysin—an experimental British artist. Gysin’s work, in fact, had hung beside Marcel Duchamp’s and Pablo Picasso’s in an exhibit in Paris in 1936.⁵ In *The Third Mind*—a book he co-wrote with Gysin in 1978—Burroughs reflects that “cutting and rearranging a page of written words introduces a new dimension into writing enabling the writer to turn images in[to] cinematic variation. Images shift sense under the scissors,” Burroughs noted. For example: “Smell images to sound, sight to sound[;] sound to

2 William Burroughs and Brion Gysin, *The Third Mind* (New York: Viking Press, 1978), 96.

3 Allen Hibbard, *Conversations with William S. Burroughs* (Jackson: University Press of Mississippi, 1999), 82.

4 Harris and MacFayden, *Naked Lunch* @ 50, 102.

5 Sylvere Lotringer, *Burroughs Live: The Collected Interviews of William S. Burroughs 1960-1997* (Los Angeles: Semiotext(e), 2001), 749.

kinesthetic,” even the inexplicable shifts intended by “tasting sounds smelling forms.”⁶ In cutting up the writing, the author makes it impossible for scenes or fragments to relate to each other temporally. So, they relate spatially. And in this spatial relation, the novel comes to rely on the same representative logic as painting on canvas.

The synaesthetic experience Burroughs sought to evoke reveals one of his grand intellectual aims; namely, the wholesale overthrow of established logic and order. If Burroughs, acting as omnipotent author, could displace sentences logically tethered to the conclusion of a book and insert them into the introduction, a case could be made for the interchangeability of space and time. In escaping prescriptive narrative order, Burroughs wanted to assert the possibility for simultaneity at the choice of the master/artist figure (in this case, himself). In a 1986 interview, Burroughs posited a connection between this ambition and his narrative impulse in *Naked Lunch*: “We know that things are happening simultaneously, but there’s no way of doing that on the page [which is my aim with] the picaresque tradition.”⁷ Burroughs’ stylistic technique, then, also served practical ends: just as the world existed in all its confusing simultaneity, so he could now represent it.

In analyzing Burroughs’ various motivations for using the cut-up, however, one must not disregard his subscription to its structural coherence. That is to say, Burroughs earnestly believed in the simultaneity of time and the overlappings of time and space evoked by the cut-up. Far from propounding a mere intellectual frivolity for its own sake, he appropriated the cut-up in order to inherit the literary tradition of realism—at least, in his own mind. In an essay written in 1993, Burroughs notes:

Writing is still confined in the sequential representational straightjacket of the novel, a form as arbitrary as the sonnet and as far removed from the actual facts of human perception and consciousness as that fifteenth-century poetical form. Consciousness is a cut-up; life is a cut-up. Every time you walk down the street or look out the window, your stream of consciousness is cut by random factors.⁸

This defense clarifies the statement Burroughs aims to make: given a crowd, the assortment of people, objects, and their relative locations result from total randomness at the instant they are framed by an observer. Thus, their arrangement is a collage—or a cut-up.

Endeavoring to represent this ubiquity-of-collage on the page, Burroughs would extract words, sentences, and pages, and assemble them according, only, to axioms of randomness—axioms immediately mistaken for arrogant gestures of absurdity. Gysin himself illuminated this rationale, arguing in 1972 that:

6 Burroughs and Gysin, *The Third Mind*, 32.

7 Lotringer, *Burroughs Live*, 628.

8 William Burroughs, *The Adding Machine: Selected Essays* (New York: Arcade Publishing, 1993), 61.

the cut-up method treats words as the painter treats his paint, raw material with rules and reason of its own [...] abstract painters found that the real hero of the picture is the paint.⁹

In fact, Gysin's assessment offers a particularly accommodating insight, given Burroughs' appraisal of Gysin as "the only modern painter to have...spread [time] out spatially on the canvas." Gysin's assessment also engages Burroughs' means of situating the intellectual statement (and critical response) of his own writing: filtering it through the lens of radical visual art.¹⁰

Though the stamp of writers like James Joyce and H.G. Wells appears in Burroughs' writing—at least, on first analysis—literary forbearers were not alone in the colonization of his psyche. In 1982, Burroughs mused: "Cezanne showed people what a fish looks like from a certain angle and under a certain light [...] at first there's always some [...] rejection, and then [...] the expansion [...] is accepted and becomes part of the general awareness."¹¹

Clearly then, Burroughs' intellectual and aesthetic impulse is grounded, too, in a school of visual avant-gardism. Considering prerogative, then, one can detect a parallel between Burroughs and the avant-garde artist Duchamp, who also dedicated his career to subverting logical structures of representation. Just as Duchamp felt that painting had become a hackneyed medium in its confinement to the realm of the visual (at the hands of the Cubists), Burroughs felt that prose had become irrelevant in its ultimate reduction to words arranged in a comfortable order. The art critic and historian Gerard-Georges Lemaire articulates this mutual ambition of intellectual expansion:

The reading of [a cut-up] is no longer external to the writing, its adventitious substitute. What comes after the writing and necessarily presupposes that the writing itself is the exterior and transitory substitution of a thought already [and] always identical with itself before any substitution [...] Duchamp's *Grand Verre* is helpful in understanding this: the eyes move along the page, obliterate it, and perceive beyond it—with the support of its constitutive traces—a series of windowpanes on which are printed, pasted, designed, and scattered the other elements of the book, placed not in a monist perspective but in a pluralistic perspective obeying an unknown logic.¹²

The images arrayed on the panes of Duchamp's Large Glass served only to summon intellectual tropes that, in their final abstraction, elided representational directness. The significance of the chocolate grinder, for example, inheres in its suggestion of the suitors' fate. The mechanization of the grinder itself is only the predicate of Duchamp's metaphor. Similarly, the cut-up sentences on Burroughs' pages served only as a point of intellectual

9 Hibbard, *Conversations with William S. Burroughs*, 67.

10 *Brion Gysin: Calligraphies Permutations Cut Ups* (Paris: Galerie de France, 1987), unnumbered introductory page.

11 Hibbard, *Conversations with William S. Burroughs*, 147.

12 Burroughs and Gysin, Lemaire's introduction to *The Third Mind*, 20.

departure—a clue to the final simultaneity of events, the ultimate permeability of the space-time envelope. Later in the same essay, Lemaire explicitly claims Duchamp as Burroughs' predecessor and alludes to Duchamp's "Rendezvous du Dimanche 6 février 1916," in which four unrelated texts were arranged on four corners of a square.¹³ The outward order of this arrangement questions the logic internal to the panels themselves. Burroughs might not have been aware of this piece, but the parallels between its message and the message of his own work can be traced from a contemporary vantage. The proximity of Duchamp's four texts spread out on four corners of a board suggests four pages out of a Burroughs novel spread out in relation to each other—emphasizing, again, the predominance of spatial over temporal relations in his work.

In his appraisal of the cut-up technique and its ability to transcend the confines of traditional speech, Burroughs invoked the work of Alfred Korzybski. Famed for his formalization of General Semantics, Korzybski wrote two books that would have a major influence on Burroughs' linguistic trajectory and intellectual idiom: *Science and Sanity* and *Manhood of Humanity*. Burroughs reflects in *The Third Mind*,

One of the great errors of Western thought [is] the whole either-or proposition. [...] Remember Korzybski and his idea of non-Aristotelian logic. Either-or thinking is one of the great shackles of Western civilization. Cut-ups are a movement toward breaking this down.¹⁴

One of Burroughs' main problems with such "either-or" thinking lay that the polarities it enforced: emotion/intellect, reason/instinct. For Burroughs, these polarities simply *do not* correspond to the mechanics of the human nervous system. In Korzybski's pages, Burroughs discovered a means of constructing language to promote the expansion of consciousness, evade thought-control, and gesture toward progressivism.

Though his suspicions seem dated today, Burroughs earnestly believed that those in power during his lifetime exploited the Cold War threat in order to control thought and stifle consciousness expansion. He admitted these anxieties to Ginsburg as early as 1961. If an experimental linguistic schema offered the potential for intellectual subversion, then, Burroughs would seize upon it. By 1968, Burroughs had distilled this fear and reappropriated Korzybskian principles. The desirability of not writing in a traditionally linear fashion, Burroughs felt, was that "verbalization got us precisely where we are: war is a word. The whole war universe is a verbal universe [...] it would seem desirable to explore alternate methods of communication."¹⁵ Little did Burroughs know that this spirit of resistance would attract the speculation of literary critics. In his 1987 essay "Across the Wounded

13 Burroughs and Gysin, *The Third Mind*, 14.

14 Burroughs and Gysin, *The Third Mind*, 6.

15 Hibbard, *Conversations with William S. Burroughs*, 79.

Galaxies: Interviews with Contemporary Science Fiction Writers,” Larry McCaffery writes of Burroughs:

The postmodernist quality of his work derives [...] from the formal methods he has devised to assert that the central threat facing modern humanity involves the control of individuals through an increasingly sophisticated system of technologically produced words [and] images.¹⁶

Before weighing Burroughs’ interpretations and appropriations of Korzybski, however, it will benefit us to explore the primary texts themselves. In *Science and Sanity*, Burroughs likely focused on passages of the following nature:

All linguistic schemes...depend on a set of undefined terms. If we enquire about the ‘meaning’ of a word, we find that it depends on the ‘meaning’ of other words used in defining it. [...] In our human reactions, speech is [...] an inborn characteristic, but what special language or what special structure of language we acquire is due to environment and copying [...] unconscious, and therefore, uncritical copying.¹⁷

Such uncritical entrenchment of speech patterns is the problem to which Burroughs refers when he speaks so pejoratively of “word-lines” and their inability to render the duality of all existence.¹⁸ “Hunger,” Burroughs muses in a 1993 essay, is a word that has come within the confines of the form of cognition termed “instinct.” Though hunger originates as a neuromuscular impulse, he concludes, its satiation necessitates activation of the neurological centers of reason—where to find food, what types are edible, etc.—before physical (instinctive) satisfaction can occur. In our tendency to label something either “A” or “B,” either instinct or intellection, we thereby incapacitate any possibility of consciousness expansion.¹⁹ Korzybski alerted Burroughs to the possibility of rebelling against orthodox thought by means of upsetting the comfortable semantic order.

Burroughs’ disclosures and conversations also reflect a solid grounding in Korzybski’s *Manhood of Humanity*. Korzybski had distilled his cogitations on speech by the publication of this volume in 1921. The “false creeds” of framing beliefs and objects in words, Korzybski argues,

have been so long and so deeply imbedded in our thought and speech and ways of life [...] that we [...] unconsciously take them for granted and have to be virtually stung into an awareness of the fact that [...] they do actually reign to-day throughout the world.²⁰

16 Ibid., 172.

17 Alfred Korzybski, *Science and Sanity* (Lancaster: The International Non-Aristotelian Library Publishing Company, 1941), 21, 36.

18 Burroughs, *The Adding Machine*, 160.

19 Ibid., 160.

20 Alfred Korzybski, *Manhood of Humanity* (Lakeville: The International Non- Aristotelian Library Publishing Company, 1968), 183.

Though Burroughs does not adhere to Korzybski's ultimate claim in this work—that anyone who wants to think logically must think mathematically—he does in many places throughout his body of work claim his inheritance of Korzybski's legacy, a legacy clung to in the service of consciousness expansion. Burroughs must have had such passages from *Manbood of Humanity* in mind when he wrote in 1993 that:

artists and creative thinkers will lead the way into space because they are already writing, painting, and filming space.[...] We are not setting out to explore static pre-existing data. We are setting out to create new worlds, new beings, new modes of consciousness.²¹

For Korzybski, the deterrents of heightened consciousness were the “false creeds” of word lines; for Burroughs, they were “static pre-existing data.”

Ultimately, the cut-up technique became a multi-purpose tool in Burroughs' arsenal. It at once asserted the simultaneity of time and questioned the linear narrative. It blurred sensory boundaries and exposed the permeability of the space-time divide. In cutting up his narratives, Burroughs turned his novels into paintings and reinvigorated the non-Aristotelian discussion introduced by Korzybski. Indeed, the cut-up was an instrument of nuanced intellectual subversion—a scalpel in able hands.

On the Interpretation of Dreams...

Burroughs' status as an intellectual outlaw was not confirmed simply by his cut-up technique. His interpretation and exploitation of dreams also demands attention to that end. Early in his intellectual development, Burroughs steeped himself in J.W. Dunne's *An Experiment with Time*, published in 1927. This book was enormously influential for the young writer; Burroughs would turn to dreams for both inspiration and theoretical framework. Regarding the latter, Burroughs saw in dreams the fracture between space and time. Before considering Burroughs' incorporation of Dunne's themes and theses, then, we might consider Dunne's text itself.

In *An Experiment with Time*, Dunne asserts that dreams not only replay fragments of past events, but also forecast future events. Dunne believed that these precognitions had been displaced in time in order to enter the sleeper's mind. This faculty, Dunne alleged, was neither rare nor mystical. He did, however, resolutely subscribe to its roots in the nature of the space-time universe:

[It seemed possible that] dreams in general [...] were composed of images of past experience and images of future experience blended together in approximately equal proportions [...] the universe was, after all, really stretched out in Time, and that the lop-sided view we had of it—a view with the ‘future’ part unaccountably missing, cut off from the growing ‘past’ part by a traveling ‘present moment’—was due to a purely mentally imposed barrier which existed only when we were awake...in reality, the associational network stretched, not

²¹ Burroughs, *The Adding Machine*, 104.

merely this way and that way in Space, but also backwards and forwards in Time; and the dreamer's attention, following in natural, unhindered fashion the easiest pathway among the ramifications, would be continually crossing and recrossing that properly non-existent equator which we, waking, ruled quite arbitrarily athwart the whole.²²

This passage directly asserts the “block universe” interpretation of Einstein’s General Theory of Relativity—that of the extant past and the presently-existing future. In this view, the present is reduced to a unidirectional moving frame traveling through the “block.” In this way, any subscription of Burroughs’ to Dunne’s philosophy must be considered, unless otherwise stated, a tacit endorsement of the block universe theory.

Such an endorsement should come as no surprise, given Burroughs’ penchant for experimental systems of thought. Burroughs referenced Dunne in essays and constantly propounded his faith in dreams as source material for fiction. “Dreams are fertile material for writing,” Burroughs reflected in 1993.

I have [...] turned up a number of future references [in dreams]; but much more important is the number of characters and sets I have obtained directly from dreams.[...] I meet a character in a dream; then I may find a photo in a magazine that looks like the character.²³

Implicit in such a reflection is Burroughs’ belief in the simultaneity of present and future. In the moment of the dream (the present), an event from the future—seeing the magazine photo—has been displaced in time into Burroughs’ subconscious. That this subconscious revelation would bear influence over his art came as no surprise to Burroughs:

The unconscious is manifested through the non-dominant brain hemisphere [...] The non-dominant brain hemisphere is [also] the source of artistic and creative thought, useful intuitions and ESP [...] spatial perception.²⁴

Burroughs’ understanding of the link between dreams and spatial cognition is remarkably telling. Given his view that dreams constantly arrest and undermine the presumed linearity of time, Burroughs concluded that dreams must thus represent the point of departure from time to space. “Dreams can be regarded as a sort of training for space conditions,” Burroughs remarked to a newspaper columnist in 1981.²⁵ Refining this view twelve years later, Burroughs wrote:

The function of dreams is to train [humanity] for future conditions. I postulate that the

²² Dunne, *An Experiment with Time*, 59, 60.

²³ Burroughs, *The Adding Machine*, 36.

²⁴ *Ibid.*, 97.

²⁵ Marty McKenzie, “An Interview with William Burroughs,” *The Lone Star Review*, April 1981, 7.

human artifact is biologically designed for space travel. So human dreams can be seen as training for space conditions[...] our future [is] in space.²⁶

By “space travel,” one assumes Burroughs is referring to the travel of our minds into a spatialized *conception* of universe—not travel *in* outer space, as it otherwise suggests. But Burroughs was not simply interested in this transition of thought for its own sake. Rather, he viewed this alteration of cognition as a means of affirming higher dimensional thought altogether—a component of his conception of consciousness expansion.

This intellectual ambition, thus, marks another intersection between Dunne’s philosophy and Burroughs’. Burroughs noted in 1981,

To me the important thing [about] space exploration [is] the possibility of making a step beyond where we are into another dimension. I feel that’s what my books are essentially about, opening up that possibility of traveling to a different set of circumstances.²⁷

Dunne’s platform on this issue surpasses Burroughs’ in terms of intellectual ambition, given his explicit reference to the “fourth dimension” that would proceed from such progress. Dunne makes clear his point that this fourth dimension would not be time:

There was no help to be found in the conception of Time as a fourth dimension. For Time has always been treated by men of science as if it were a fourth dimension. What had to be shown was the possibility of displacement in that dimension. Nor did I gather much comfort from Bergson; for to tell a man who is confronted with Time clearly transposed that Time has no parts is distinctly futile. I cared not a whit whether Time were a ‘form of thought,’ or an aspect of reality, or (this was later) compoundable with Space.²⁸

Dreams, for Dunne and Burroughs, were not simply powerful as windows of precognition. Rather, they exposed the artificial barriers assumed to direct time’s flow and, thus, signaled transcendence into a spatialized conception of existence.

In attempting to grasp the true scope of Dunne’s influence (and perhaps the validity of such an influence) over artists like Burroughs, one can consider the arguments made by British novelist, political broadcaster, and essayist J.B. Priestley in his 1964 book, *Man and Time*. Dunne “may be said to have challenged the conventional positivist idea of Time on its own ground,” Priestley mused, but he “had not been visited by any mystical revelations. He was not a sentimentally poetic character, outraged by the contemporary world.”^{29,30} Though Priestley goes on to question the soundness of some of Dunne’s inferences, he

26 Burroughs, *The Adding Machine*, 137.

27 McKenzie, “An Interview with William Burroughs,” 7.

28 Dunne, *An Experiment with Time*, 55, 56.

29 J.B. Priestley, *Man and Time* (London: Crescent Books, 1964), 245.

30 By a “positivist idea of time,” Priestley most likely means the assumption that time’s unidirectionality is put to the test and “confirmed” by day-to-day empirical experience.

generally praises the revolutionary nature of Dunne's work, given the intellectual climate at the time of its publication. Predictably, Burroughs devoured and adopted its more radical insinuations.

One of Priestley's reflections illuminates Burroughs' general approach to time, and indirectly summons Dunne's legacy in the process:

A novel or a play cannot really be *about* Time [...] Time is a concept, a certain condition of experience, mode of perception, and so forth; and a novel or play, to be worth calling one, cannot really be about Time but only about the people and things that appear to be *in* Time. Some novelists [...] may be unusually aware of Time, but they have to write about something else.³¹

Is *Naked Lunch* a book about time? Though its impact rests partially upon a jarring temporal discontinuity, its plot and characters are undeniably self-sustaining. It is questionable, however, whether the novel's infamy would have accrued in the absence of its bizarre temporal schema.

El Hombre Invisible

Burroughs has never received the credit that is his due; and this oversight comes as no surprise. In fact, it was only at the pleading behest of Allen Ginsburg that Burroughs was inducted into the American Academy and Institute of Arts and Letters in 1983.³² In dismissing his writings, many critics—enamored of the hard-nosed (and perhaps, navel-gazing) rigor of their own discipline—lose sight of Burroughs' contributions to the intellectual discourse of the twentieth-century. Amid a generation of Americans who considered themselves patriotic for their fixation on the space race and the expansion of scientific frontiers, William Burroughs labored quietly toward similarly ambitious developments, albeit those without the guidance and approval of the U.S. government—a government whose policies he flouted with his openly pro-drug image. His writings and interviews disclose profound fascination with the transcendence of human thought—indeed, human *existence*—beyond space and time, the simultaneity of space-time events, and the displacements through the “block universe” that are communicated in dreams. If critics would claim death and drugs as Burroughs' abiding preoccupations, they must also account for the myriad of ruminations on consciousness expansion that riddle his prose. Burroughs lived and died as a literary outlaw. And though the intellectual contributions of the writer Norman Mailer dubbed “the most talented writer in America” continue to go unsung, they will in time garner respect and recognition.³³

³¹ Ibid., 122.

³² Morgan, Ted. *Literary Outlaw: The Life and Times of William S. Burroughs* (New York: Henry Holt and Company, 1988), 5-7.

³³ William Burroughs, Norman Mailer's introduction to *Naked Lunch* (New York: Grove Press, 1966), xii.

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A Generalized Method of Lie Symmetries for Dynamic Equations on Time Scales, and Applications

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Abstract

In this paper, we discuss the calculus of time scales¹ with respect to dynamic equations and Lie algebraic methods. The basic properties of time scale calculus are outlined. Applications of Lie theory to differential equations are generalized to dynamic equations over arbitrary time scales. Lie algebraic methods involving the evolutionary form of vector fields and corresponding symmetry groups are considered. Three new results are presented: an infinitesimal invariance criterion, a general prolongation formula for dynamic equations on time scales,

¹ It is important to mention that time scales are also often called “measure chains,” the two terms having the same meaning. As “time scale” is more common, we will adhere to this term.

and a result for the error term in the general solution when series solutions must be found. The method derived is most useful for first order equations, but also extends to higher order equations under restrictions that are satisfied in many applications. This method can be used on classes of systems of equations that have previously been difficult to solve, particularly non-linear equations. Lastly, several applications of this generalized method are discussed, and selected examples are given in economic modeling, neural networks, and population modeling.

1. Introduction

The calculus of time scales was first introduced by S. Hilger in 1988 [6]. The original purpose of the theory of time scales was to unify discrete and continuous calculus. (It is important to mention that the term “time scales” does not refer only to time, although it is a common application.) Since then, a fairly complete theory of the essentials of calculus, such as integration, partial dynamic equations, multiple, and line integrals, has been developed, though the area of Lie theory has received less attention. The purpose of this paper is to generalize a method for solving dynamic equations on time scales. We give three results, all of which are required develop a complete, deterministic method for solving systems of dynamic equations on time scales:

- A general prolongation formula for dynamic equations on time scales;
- An infinitesimal invariance criterion; and
- A result for the error term in the general solution when series solutions must be found.

The paper is structured as follows: in Section 2 we outline the basic definitions and properties of time scales (a more detailed introduction can be found in [4]) and give some examples and applications. In Section 3 we present a discussion of Lie algebraic methods for solving dynamic equations, and present the main results which allow the method to be generalized. Section 3.2 is the first section in which new results are presented. In Section 4 we discuss applications of this method, especially in the areas of mathematical modeling in economics, neural networks and biology. Finally, in the last section we present our conclusions and suggest possibilities for further study.

2. Definitions and Basic Properties of Time Scales

The motivation for the definition of a time scale is to create a unifying theory for differential equations and difference equations. Therefore, the aim is to create definitions which generalize properties of discrete and continuous functions. To this end, it can be observed that the fundamental difference between discrete and continuous functions is the domain on which they are defined. Hence, as an arbitrary time scale will serve as the domain of the functions which we will consider, the definition must generalize the

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properties of \mathbb{R} and \mathbb{Z} ; however, in order to obtain some idea of the important concept of continuity in our generalized setting, we must require that all limit points be included in the time scale. We therefore make the following definitions:

Definition 1.1: A time scale T is defined to be an arbitrary non-empty closed subset of the real line.

Definition 1.2: The forward jump operator σ and the backward jump operator ρ on a time scale T are defined by $\sigma(t) = \inf\{s \in T : s > t\}$ and $\rho(t) = \sup\{s \in T : s < t\}$. We also define $\mu(t) = \sigma(t) - t$. The function μ is referred to as the graininess of the time scale at t . The point t is called right dense if $\sigma(t) = t$ and right scattered otherwise. Similarly, t is left dense if $\rho(t) = t$ and left scattered otherwise. Also, t is called dense if it is both left and right dense, and scattered if it is both left and right scattered. We call a function defined on T continuous if it is continuous in the topology of T . It is called rd-continuous if it is continuous at right dense points and the left-sided limits exist at left dense points.

The real numbers and the integers, as well as the quantum domain, are clearly examples of time scales. An important property of time scales is that the domain doesn't have to be one of the "standard" domains, such as the reals or the integers. Instead, the domain can be irregular. This property is exploited to more accurately model mixed continuous and discrete aspects of physical systems.

Derivatives, and therefore differential equations, can also be generalized to time scales.

Definition 1.3: Let f be a real valued function on a time scale T . The delta derivative of f at $t \in T$ is denoted by $f^\Delta(t)$ and is defined to be the real number (if it exists) with the following property: for every positive ϵ there exists a neighborhood of U of t (that is, $U = (t - \delta, t + \delta) \cap T$) such that for all $s \in U$,

$$| [f(\sigma(t)) - f(s)] - f^\Delta(t)[\sigma(t) - s] | \leq \epsilon | \sigma(t) - s |.$$

A function $f: T \rightarrow \mathbb{R}$ is said to be delta-differentiable at a point t if its delta-derivative exists at t , and is called delta-differentiable in an interval I if it is delta-differentiable at every point of I .

If $\sigma(t)$ is replaced by $\rho(t)$ in the above definition, we obtain the definition of the nabla-derivative of f at t , denoted by $f^\nabla(t)$, and exactly the same definitions apply regarding differentiability.

Example 1.4: Consider the time scales \mathbb{R} and \mathbb{Z} . In \mathbb{R} the definition of the derivative shows that $f^\nabla = f^\Delta = f'$, given that f is a continuously differentiable function. If f is instead defined on $[a, b]$, then $f^\Delta(a)$ is the right hand derivative of f at a , assuming it exists; and

$f^\nabla(b)$ is the left-sided derivative at b , if it exists. In \mathbb{Z} , f^Δ is the forward difference Δf , and f^∇ is the backward difference.

Many results, such as the product, quotient and power rules, apply to differentiation on time scales; however, there are several exceptions. The most important is the chain rule, which is considerably more complicated on arbitrary time scales.

Lastly, higher order derivatives are defined by repeatedly taking the delta or nabla derivatives of a function. Partial delta and nabla derivatives of a function defined on several variables in multiple time scales are found by differentiating with respect to one time scale, while keeping all other variables constant.

The next important point is to generalize integral calculus to arbitrary time scales. A function $f: T \rightarrow \mathbb{R}$ is called regulated if at all right dense points its right-sided limit exists and at all left dense points its left-sided limit exists. A function F is called an anti-derivative of f if f is the delta-derivative of F on T , in an analogous way to the continuous case. Hilger [7] proved in his original paper on time scales that any regulated function f on T has an anti-derivative F , and that on the interval $I = [a, b] \cap T$, the value of $F(b) - F(a)$ does not depend on the choice of F , as long as it is an antiderivative of f . This allows us to define the Cauchy integral of a regulated function $f: T \rightarrow \mathbb{R}$, defined on I and with anti-derivative F , by $\int_a^b f(t) \Delta t = F(b) - F(a)$. The fundamental theorem of calculus justifies this definition. Riemann integration can be also be defined on arbitrary time scales, and the fundamental theorem of calculus can be formally proven in this setting. However, as we will be interested in dynamic equations, where all functions are assumed to be continuously differentiable, the above definition will not present a loss of generality and will suffice for our purposes.

This concept of integration on time scales has many applications. For example, suppose that an insect population dies out every winter, and its growth rate is modeled by the function f at all other times. Then f is defined on the periodic time scale, and integration over this time scale will give the overall change in the population over time more easily than methods using continuous calculus will, as it will not be necessary to integrate over each integral separately, but only the entire time scale.

A dynamic equation on a time scale T is an equation involving t , a function $f: T \rightarrow \mathbb{R}$ and the delta or nabla derivative of f . Initial and boundary conditions are also important in the study of dynamic equations on time scales. For example, the solution to the equation $x^\Delta(t) = p(t)x(t)$ is given by $x(t) = x(0)e_p(t, 0)$ where e_p is the generalized exponential function. Partial dynamic equations are defined similarly to the continuous case. We now have the necessary material established to examine the interaction between functions and dynamic equations on time scales and Lie groups.

3. Lie Theory on Time Scales

3.1 Preliminaries

We will be primarily interested in extending the method of solving differential equations through symmetry groups to dynamic equations on arbitrary time scales. We want to define the concept of the Lie symmetry algebra of a symmetry group for a system of dynamic equations on time scales as well as the formulas which allow the method to be implemented.

We will be interested in dynamic equations of the form

$$E(t, u(t), \sigma_{\alpha_i} u^{\Delta_i}(t), \sigma_{\beta_{ij}} u(t), u^{\Delta_k}(t), \dots) = 0.$$

We will also consider systems $\Delta = (E_1, \dots, E_k) = 0$. In order to proceed as in the continuous case, we must first generalize the concept of prolongation. The function $u = f(x)$ will be identified with its graph as in the continuous case, and a solution will be defined as a function whose graph lies on $S\Delta$, the subspace of the prolonged space $M^{(n)}$ which satisfies the system. Such a graph is a subset of $X \times \mathbb{R}^k$, where T is the Cartesian product of time scales which is the domain of f , and k is the number of dependent variables. An operation g will be called a symmetry of the system if, whenever $(x, u) \subseteq S_\Delta$, $u = f(x)$, $g(x, u) = (x_1, u_1)$ is also a solution, i.e. that the graph of $g \cdot f = f_1(x_1)$ lies in $S\Delta$ if the graph of f does. The symmetry group G must be a continuous group of transformations, although the solutions themselves are defined on time scales. The reason for this is that an evolutionary transformation can map an element of the range of a time scale function (an element of \mathbb{R}) to any other element of \mathbb{R} , so that all real values of λ must be used to obtain the full one-parameter symmetry subgroup. In other words, because g maps u to u_1 , g maps \mathbb{R} to \mathbb{R} , so that the symmetry group itself is a Lie group of continuous transformations. Therefore, $\exp(\lambda v)$ is a continuous function of λ for a one-parameter subgroup. The particular solution f is a real valued function on a time scale. The function Δ is a real valued function whose domain is a Cartesian product of time scales (the independent variables) and \mathbb{R}^k (the functions u). Of course, we must first define the prolongation of G and its infinitesimal generators v . The variables will be assumed to be continuous, with the equations in specific time scales (the solutions can then be restricted if necessary), and the connection between the generators v and one-parameter subgroups will be the same as in the continuous case; and the transformed functions under G are found in the usual way. The subgroup generated by v is denoted by $\exp(\lambda v)$.

The next objective is to generalize the idea of prolongation. Here, the prolonged action of G acts on the delta and nabla derivatives of u , as well as backward and forward jump operators. Suppose that G acts on a set M (not necessarily a manifold,

as $M = T \times \mathbb{R}^k$ with coordinates (x, u) , where $u = f(x)$ is a q -valued function in p variables and $g \cdot (x, u) = (x_1, u_1)$. Here we consider both shift operators and derivatives in combinations of the form $u^{\wedge \alpha}$ where α is a product of jump operators (shifts) and \wedge is a product of delta and nabla derivatives. We will use the notation $u^{\wedge \alpha} = \alpha u^{\wedge} = \alpha \wedge u$. The order of this operation is defined to be the sum of the total number of shifts and derivatives performed on u . The prolonged action of G is defined to be the action of G on x and u , as well as on the shifts and derivatives of u . Given a real function f , defined on the time scales $T = T_1 \times \dots \times T_p$, define $pr_T^{(n)} f(x) = (f^{(n)}(x))$, where $f^{(n)}(x)$ consists of all $\alpha_I f^{\wedge J}$, where α and \wedge are, respectively products of delta- and nabla-derivatives and shift operators taken over unordered multi-indices I and J , where $|I| + |J| \leq n$. If $u = f(x) = (f_1(x), \dots, f_q(x))$, denote $u_T^{(n)} = pr_T^{(n)} f(x) = (f, f_1^{(n)}, \dots, f_q^{(n)})$, and the space of all $(x, u^{(n)})$ will be denoted by $M^{(n)} = X \times U^{(n)}$. If G acts on M according to $g \cdot (x, u) = (x_1, u_1)$ then we define the prolonged action of G by $pr_T^{(n)} g \cdot (x, u) = (x_1, u_1^{(n)})$, similarly to the continuous case.

This concept will allow us to construct symmetries of dynamic systems. In dealing with these systems, Δ will represent both the equation defining the system and the corresponding sub-variety S_Δ . Next, suppose that the one-parameter subgroup H corresponds to the infinitesimal generator v . If we denote $pr_T^{(n)} H = \{pr_T^{(n)} h\}$, then the prolongation of v , denoted by $pr_T^{(n)} v$, is defined to be the infinitesimal generator of the prolonged subgroup $pr_T^{(n)} H$. If v has the form $v = \sum_{i=1}^p \zeta^i \partial_{x_i} + \sum_{k=1}^q \phi_k \partial_{u_k}$, then it is clear that the the prolongation of v will be given by

$$pr_T^{(n)} v = \sum_{i=1}^p \zeta^i(x, u) \partial_{x_i} + \sum_{k=1}^q \sum_{I, J} \phi_k^{I, J} \partial_{u_k^{I, J}}$$

for some functions $\phi_k^{I, J}$, the sum extending over all multi-indices I, J where $|I| + |J| \leq n$, and $u_{I, J} = \alpha_I u^{\wedge J}$. Our objective is therefore to first determine an analogue of the infinitesimal criterion involving the prolongation of vector fields, and then to find an explicit formula for the prolongation of v in terms of v . In addition, the concept of local solvability must be generalized, in order to obtain a complete infinitesimal criterion. This can be done in essentially the same way as in the continuous case. For a system Δ , we say that it is locally solvable if at each point $p_0 = (x_0, u_0^{(n)})$ of S_Δ , there exists a smooth solution $u = f(x)$ defined in some neighborhood of p_0 such that $u_0 = pr_T^{(n)} f(x_0)$. The system is non-degenerate if it is locally solvable and of maximal rank. This essentially says that the initial value problem corresponding to the system is solvable in some neighborhood of any point.

3.2 Main Results

In this section we present three main results: an infinitesimal invariance criterion, a general prolongation formula for dynamic equations on time scales, and a result for the error

term in the general solution when series solutions must be found. First, we will need the following generalization of a known theorem concerning invariance of algebraic systems. [13] describes this some of the subsequent theorems in the continuous case.

Theorem 3.1: Let G be a connected Lie group of transformations acting on $M = T \times \mathbb{R}^k$. Let Δ be a function defined on M , such that $\Delta(\exp(\lambda x))$, $x \in M$, is a smooth function of λ . Suppose that the one-parameter subgroup consists of evolutionary transformations $g\lambda(x) = \exp(\lambda x)$, so that the time scale variables are constant under g . Suppose also that Δ is smooth in the topology of M . Then Δ is an invariant of the one-parameter subgroup $\{g\lambda\}$ if and only if $v(\Delta) = 0$ for all $x \in M$, where v is the infinitesimal generator of $\{g\lambda\}$.

Proof: Let $x = x_T \times y$, where $x_T \in T$ and $y \in \mathbb{R}^k$. Then as g is evolutionary, $\exp(\lambda x)x_T = x_T$. Therefore, $\Delta(\exp(\lambda v)x) = \Delta(\exp(\lambda v)y)$, since x_T does not vary with λ . Therefore, by the chain rule, $\frac{d}{d\lambda}\Delta(\exp(\lambda v)x) = \sum_{i=1}^k [\frac{d}{d\lambda}\exp(\lambda v)]_i x_i \frac{\partial \Delta}{\partial y_i} \exp(\lambda v)x$, because y is a continuous independent variable for Δ . This is also because even if x_T is involved in the transformation equation for y , it does not vary with λ , so that $\Delta(\exp(\lambda v)x)$ can be written as $\Delta(y(\lambda))$, and the chain rule is only applied to the variables y . By the properties of $\exp(\lambda y)$, this implies that $\frac{d}{d\lambda}\Delta(\exp(\lambda x)) = \sum_{i=1}^k v^i(\exp(\lambda y)x) (\frac{\partial \Delta}{\partial y_i} \exp(\lambda y))$. As v is evolutionary, we therefore obtain the identity

$$\frac{d}{d\lambda}\Delta(\exp(\lambda v)x) = v(\Delta)[\exp(\lambda y)x].$$

From this it can be seen that Δ is constant with respect to Δ if and only if $v(\Delta)$ is identically 0. It follows that Δ is an invariant of the one-parameter subgroup if and only if $v(\Delta) = 0$. ■

This result shows that, although M is not necessarily a manifold, we can still obtain a useful invariance criterion for the symmetry one-parameter subgroups. [10] illustrates the use of this criterion for the case of fixed difference equations. Later we will give examples for arbitrary time scales.

Letting Δ be a vector-valued function, apply the above theorem to each component and each one-parameter subgroup. This gives an infinitesimal invariance criterion for algebraic systems. The next several theorems apply this to the prolongation of G to obtain an infinitesimal invariance criterion for dynamic equations.

Theorem 3.2: Let M be any open subset of the space $X \times U$ and let $\Delta(x, u_T^{(n)})$ be an n th order of dynamic equations on M , and let $S_\Delta \subset M^{(n)}$ be its corresponding subvariety. Let G be a group of transformations acting locally on M , and suppose that S_Δ is invariant under G . Then G is a symmetry group of the system, meaning that the $g \cdot f$ is a solution whenever f is.

Proof: Let $u = f(x)$ be a solution. By definition, this means that the graph of the prolongation of f , $\Gamma_f^{(n)}$, lies entirely in the sub-variety of the system. Furthermore, if g is such that its transformation of f is defined, then by the definition of prolongation, the graph of the prolongation of $g \cdot f$ is the transformation of the graph of the prolongation of f under the prolonged action of g , i.e. $\Gamma_{g \cdot f}^{(n)} = pr_T^{(n)} g(\Gamma_f^{(n)})$. Because S_Δ is an invariant of G , it follows that this graph lies entirely in S_Δ . But this, by definition, says that $g \cdot f$ is another solution. It follows that G is a symmetry group of Δ . ■

It is important to note that this theorem follows naturally in a similar manner to the continuous case, yet is still useful in obtaining the criterion in the next result, illustrating the usefulness of the concept of time scale calculus. Combining the last two results immediately gives the following infinitesimal criterion, which again mirrors the continuous case.

Theorem 3.3: A system is called non-degenerate if it is both of maximal rank and locally solvable. Let $\Delta_T^{(n)}(x, u)$ be a system of dynamic equations on a manifold $M^{(n)}$, and suppose that G is a group of transformations acting locally on M . G is a symmetry group if and only if

$$pr_T^{(n)} v[\Delta_T(x, u)] = 0$$

whenever $\Delta = 0$, for all component functions of Δ and every infinitesimal generator v of G .

Proof: Because of Theorems 3.1 and 3.2, it suffices to show that the sub-variety S_Δ invariant of $pr_T^{(n)} G$ if G is a symmetry group. Let $(x_0, u_0^{(n)})$ be a point of this variety. Because Δ is locally solvable, there exists a function $u = f(x)$ which is a solution in some neighborhood U of $(x_0, u_0^{(n)})$ such that $u_0^{(n)} = pr_T^{(n)} f(x_0)$. Let g be a transformation in G defined by $g \cdot (x, u) = (x_1, u_1)$, such that $g \cdot (x_0, u_0)$ is defined. Then a suitable domain of f can be chosen so that $g \cdot f$ is defined. This implies that $g \cdot f$ is again a solution to the system. Lastly because $pr_T^{(n)} g \cdot (x_0, u_0^{(n)}) = ((x_0)_1, (u_0)_1^{(n)})$, it follows that, as this is a point on a solution, it lies on S_Δ . This shows that the sub-variety of the system is invariant under $pr_T^{(n)} G$, and the result follows. ■

The last two theorems illustrate that the Lie symmetry formalism for differential equations extends naturally to dynamic systems on arbitrary time scales. The next objective is to find suitable formulas for the prolongation which can be used in the application of this method. The difficulty is that the standard chain and inverse rules do not completely extend to arbitrary time scales. The solution to this problem involves two parts. The first is to find suitable restrictions which give a general prolongation formula for a system of dynamic equations, where evolutionary vector fields can be used to find an explicit

prolongation formula. The second is to find a method for solving the resulting determining equations. The difficulty is that the prolongation formula involves total derivatives on time scales, and the following chain rule (see [4]) on time scales shows that in general the total derivative of a function is not easily found. However, a power series method can be used to solve the total dynamic equations which determine the symmetry algebra.

Theorem 3.4 (Chain Rule): Suppose that f and g are real valued functions such that f is continuously differentiable and g is delta-differentiable. Then $f \circ g$ is delta differentiable, and its derivative is given by

$$(f \circ g)^\Delta(t) = \left[\int_0^1 f'(g(t) + b\mu(t)g^\Delta(t))db \right] g^\Delta(t).$$

Given a vector field in evolutionary form, we can generalize the prolongation formula to arbitrary time scales. Furthermore, the formula also applies to generalized symmetries. The notation $\alpha_I \wedge_J u$ is used to denote $(u^{\wedge J})^{\alpha_I}$. The prolongation formula also applies to generalized symmetries, if these are required.

Theorem 3.5: Suppose that $v = \sum_{k=1}^q \phi_k(t, u, u_T^{(n)}) \partial_{u_k}$ is an evolutionary vector field, where ϕ is smooth and the total delta derivatives of ϕ up to order n exist. Then

$$pr_T^{(n)} v = v + \sum_{k,I,J} \alpha_I^T \wedge_J^T \phi^k \partial_{\alpha_I(u_k) \Delta_J}$$

The sum is taken over all indices such that $|I| + |J| \leq n$, and the total jump operator α^T is defined analogously to the total derivative.

Proof: To verify the formula, we must explicitly determine the prolonged action of the group G which v generates on u . Let the action of G be defined by $g_\lambda \cdot (t, u) = (t, \phi_\lambda(t, u, u_T^{(n)}))$, where $\frac{d\phi}{d\lambda} |_{\lambda=0} = \phi$. Then

$$pr_T g_\lambda(u^{\alpha_I \wedge_J}(t)) = \alpha_I \Delta_J \phi_\lambda(t) = \alpha_I \wedge_J \phi(t, u(t), u_T^{(n)}(t)) = \alpha_I^T \wedge_J^T \phi(t, u, u_T^{(n)})$$

by the definition of the total derivative with respect to the index J . Because ϕ is smooth (in the time-scale topology), differentiation processes can be interchanged on ϕ , and it follows that $\frac{d}{d\lambda} |_{\lambda=0} \alpha_I^T \wedge_J^T \phi = \alpha_I^T \wedge_J^T \frac{d}{d\lambda} \phi |_{\lambda=0} = \alpha_I^T \wedge_J^T \phi$ which verifies the coefficient $\partial_{\alpha_I(u_k) \wedge_J}$ and the claim of the theorem is verified. ■

As we are interested in transformations of the function u (because any symmetry can be determined by how it acts on u) it suffices to consider evolutionary vector fields, and the above theorem gives a sufficient criterion for invariance, and can therefore be used to find the general solution. However, because the chain rule and total derivative

formula for time scales are not as convenient as those for the continuous case, the method is not computationally useful if it is applied directly in the manner which is used in the continuous case. The method can still be made computationally efficient by expanding the symmetries in a Taylor series, which will give a series solution (as the total derivative of a polynomial can be explicitly found). Of course, expanding in a multivariate Taylor series (in the continuous sense) assumes continuous differentiability at least up to some given order; however, in the great majority of applications to physical modeling, this will at least be the case on piecewise intervals. A series expansion on a general time scale can be used, though this is not as computationally viable. Also, in [10] it is demonstrated that a continuous series can be used for difference equations. Lastly, as examples discussed later show, the continuous expansion will not present too great loss of generality for the purpose of physical applications, so it is ultimately the preferable method. Furthermore, as we are assuming variables to be continuous, this is not too great a loss of generality, and the solution can be restricted to a specific time scale after it is found. Calculation of the total delta derivative of polynomial is described in both [10] and [2].

There are two advantages to this method. First, because the determining equations for the symmetry algebra are usually in the form of numerous elementary equations which can be easily solved, the series solution obtained for each vector field can often be interpreted as the series of a known exact function or combination of functions, which will give an exact general solution. An example of this occurs in [10], and because of the relative simplicity of the determining equations when compared to the original equation (as described in [13] and [10] for the familiar cases), this will often be the case. However, when it is not the case, it will be necessary to use the series solution for the symmetry algebra to find a numerical general solution in the form of an approximating polynomial. This will suffice for applications, as it turns out that there is a sufficiently strong result for the error bound given for the general solution. The second main advantage of the method is that the prolongation method will reduce the equation to simpler determining equations for the series, so that it will be easier to find the explicit Taylor polynomial by this method than by directly solving for a series solution from the equation itself. Also, the resulting solution will often be more general, as all of the symmetries can be used to find all possible solutions (which is already an advantage in the continuous case).

Next, suppose that after using the power series method for the determining equations, the approximate vector field v in the symmetry algebra has been found, where $v = \sum_{k=1}^p Q_k \partial_{u_k}$, and Q_k is approximated by the the multivariate Taylor polynomial $P_{n,k}$ of order n . Then a Lie series can be used to find the one-parameter subgroup of this polynomial. Specifically, the formula for a Lie series expansion implies that $\exp(\lambda v_k)(x, u) = \sum_{m=1}^{\infty} v_k^m(x, u) \frac{\lambda^m}{m!}$. Therefore, exponentiating the field v when written as a power series using a Lie series will give a series expansion for the one-parameter subgroup g_k of v_k . For if v is given as a series, then v^m is also a power series, so that the entire Lie series can be written

as a power series in x , u and λ . The terms involving indices up to some order j can then be found, and this polynomial will represent an expansion $E_{j,k}$ of order j in the Taylor series form. As a function can have at most one Taylor series expansion, it follows that this polynomial is the Taylor polynomial of degree j for g , and therefore that the corresponding error term is the ordinary error term for an expansion in terms of λ , x , and u for g_k . Lastly, as the general solution is found by composing all of the series expansions of one-parameter subgroups with a known solution, this composition will give another series (from which the polynomial of degree i can be found) for the general solution. This polynomial could also be derived from an arbitrary linear combination of the basis elements of the Lie algebra. By the same reasoning as above, the error term corresponding to this polynomial will be given by the standard Taylor formula for the error of a multivariate polynomial approximating the solution in x , u and λ .

[2] describes the calculation of the total time-scale derivative of ordinary Taylor polynomials, and [10] describes an application of this to finite difference equations. However, for non-uniform time scales, it may not be possible to obtain a solution by assuming x to be continuous and applying the continuous Taylor series. In this case, apply the multivariate time scale Taylor polynomial (in terms of the functions g_n) to the total differential equation for the Lie algebra. For a given time scale, the total derivative of the functions g_n can be found. Once this is done, a series expansion for v in terms of the functions g_n can be found. Then, substitute this into the Lie series to obtain a representation of the one-parameter subgroup. As the Lie series is a continuous series, and the Taylor series for v is a time scale series, the final representation of the symmetry of the system will be a Taylor series representation, in terms of the functions the functions g_n for x and u , and the functions λ^n . Truncations of this series will then give approximate solutions.

Having established a reasonable result for the error term in the case that an exact solution cannot be found, we have developed a complete, deterministic method for solving systems of dynamic equations on time scales, which we now summarize.

To solve a system of dynamic equations $\Delta=0$:

1. For an element of the symmetry algebra v , set $pr_T^{(n)}v = 0$, and then set $\Delta=0$ and simplify.
2. Expand v in a Taylor series, set the resulting expression equal identically to zero, and solve for the series for v .
3. Once this has been done to obtain series expansions for the vector fields which span the symmetry algebra, use known series expansions to determine any exact vector fields which can be obtained.
4. If the symmetry algebra can be found exactly, then use the standard method to find the symmetry group and then the general solution.
5. If the symmetry algebra cannot be found exactly, then use the above error result to

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obtain some suitable termination procedure to determine the number of terms in the series needed, and then determine the approximate symmetry group. Then, use some known solution or initial condition to determine the approximate general solution.

6. In either case, use initial conditions and/or Cauchy data to find the particular solution.

4 Examples and Applications

The main usefulness of the results of this paper comes from the combination of the generality and applicability of the theories of time scales and Lie groups. Dynamic equations on time scales provide an extension of discrete and continuous calculus, and therefore provide accurate mathematical models of a much greater variety of situations than either the discrete or continuous methods. Therefore, these equations can be used to describe a variety of situations in different fields, so that methods for determining their solutions are highly useful. The method of Lie symmetries has applications in that it unifies and extends most other methods for solving differential equations, and is therefore often the most generally applicable method and yields the most useful solutions. In particular, the method often reduces nonlinear equations to simpler ones, and in this case direct methods and even the power series method often fail. However, as described in [13] and [10], the Lie group method often applies to these equations. Therefore, the above results are useful because they generalize the Lie symmetry method to the case of arbitrary time scales, and can therefore be used to solve difficult problems in the variety of situations where time scales arise.

Before we give concrete applications of this method, consider a simpler example for the sake of illustration. Let u be a function defined on the time scale $T \times X$ by the equation $u^\Delta(t) - u^\Delta(x) = u_t - u_{xx} = 0$. Here we will adopt a simplified ansatz (discussed below) similar to that used in [10] for the discrete heat equation. Therefore, we write the evolutionary symmetry vector field to be determined as $v = [pu + gqu + ru_{xx}] \partial_u = Q \partial_u$, where p , q , and r are functions of x , t and σ , σ being the jump operator in either t or x . Here the jump operators are defined as acting on u , that is $\sigma u = u^\sigma$. The infinitesimal invariance criterion implies that for v to be a symmetry, $Q^t - Q^{xx} = 0$ whenever $u_t - u_{xx} = 0$. Substituting the expression for Q into this equation and evaluating the total derivatives of Q gives a dynamic equation for Q . Then, the heat equation and its consequences can be used. Use the vanishing of the heat equation to eliminate u_{xx} , u_{xxx} and u_{xxt} when they appear in the equation for Q . Then the terms involving u_{tt} cancel. The equation will then become one involving u_{xt} , u_t , u_x and u linearly. Requiring the coefficients of these to vanish gives a system of equations for p , q and r . These calculations will be analogous to the calculations in [10] for the finite difference case. Therefore, the results will be the time scale analogs of the functions p , q and r determined there. Carrying out the calculations gives the following system:

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$$p_x = 0$$

$$2(q_x)\sigma_x - (p_t)\sigma_t = 0$$

$$-(q_t)\sigma_t + (q_{xx})\sigma_x^2 + 2(r_x)\sigma_x = 0$$

$$-(r_t)\sigma_t + (r_{xx})\sigma_x^2 = 0.$$

These equations can now be solved in a manner analogous to the one presented in [10]. The solutions will be the time scale analogs of the discrete solutions. Denote the n th Taylor function on T by $g_{T,n}$, and similarly for X . The solution to the system is then

$$p = g_{T,2}(t, 0)p_2 + tp_1 + p_0$$

$$q = kx(p_1 + 2tp_2)\sigma_t\sigma_x^{-1} + tq_1 + q_0$$

$$r = cg_{X,2}(x, 0)p\sigma_t^2\sigma_x^{-1} + ltp_2\sigma_t + mxq_1\sigma_t\sigma_x^{-1} + \gamma$$

Here c , k , m and l are constants. pi , qi and γ are functions of the shift operators and of the graininess μ . It follows from the infinitesimal invariance criterion that a vector field in the above evolutionary form given by these functions determines a symmetry of the generalized heat equation. The arbitrary functions give an infinite dimensional algebra, but as pointed out in [10], a six-dimensional sub-algebra can be chosen by determining six different choices of the coefficient functions. This algebra can then be exponentiated to give a six-parameter subgroup of the symmetry group. Noting that any constant is a solution, new solutions can be found from these symmetries. In [10], the six-dimensional algebra is isomorphic to the continuous equation's algebra, and this will analogously be the case here. Among the symmetries for the generalized heat equation are scalar multiplication, an analog of the Gallilean boost operator, and the addition of any two solutions to the equation.

Next let us consider several applications of the solution to dynamic equations to mathematical modeling.

One of the most prominent applications of time scales is in economics. For example, the time scale model gives equations for the maximal lifetime utility subject to budget constraints which is more accurate and versatile than the standard models. As described in [11], if C is the constraint function, and U is the utility, than U is modeled by the equation

$$[u'(C(t))]^\nabla = \frac{\delta - r}{1 + \delta\nu(t)}u'(C(t))e$$

where u is a function directly related to U , and δ and r are parameters associated with the

constraints. Therefore, the substitution $y(t) = u'(C(t))$ will give a dynamic equation for the maximal utility. Although this is a relatively simple linear equation, it nonetheless illustrates the applicability of the above method to dynamic equations. A more interesting example appears in the theory of neural networks. One improved model ([11]) for the BAM neural network is based on the system of equations

$$x_i^{\Delta}(t) = -a_i(x)[b_i(x) + f_i(t, y)]$$

$$y_j^{\Delta}(t) = -c_j(y)[d_j(y) + g_j(t, x)].$$

In this case, a , b , c , f , and g are known functions. One reason that the Lie symmetry method is useful in this case is that the expressions for f and g in terms of x and y are in practice very complicated, and may in fact involve integrals of x and y , so that this is not an ordinary system of differential equations. However, as the partial derivatives of both of these expressions will depend only on x , y and t , the determining equations for the symmetry Q found using the prolongation formula will (for a given network with known functions a , b , c , f , and g) give a linear total differential equation on the time scale T for $Q(t, x, y)$. This equation can then be solved by the power series method described above (by setting the coefficients of x , y , etc. equal to 0,) so that a general solution can be found much more easily than by ordinary methods. Because of the complicated nature of f and g , this example is more limited than the previous one, though it nonetheless illustrates (at least for the simpler cases in this application) the use of this paper's method for simplifying the solution of dynamic equations.

As another application, consider the generalized nonlinear equation $E = u^{\Delta\Delta}(t) + u^{\Delta}(t) = 0$, similar to the difference equation given in [10]. If $v = \phi \partial_u$ is a symmetry, then using the prolongation method implies that ϕ satisfies the equation $\phi^{tt} + 2u\phi = 0$ whenever $E = 0$. This reduces the equation to a linear total dynamic equation, and in [10], the use of a power series method to find the symmetry algebra is described for the difference equation case. Therefore, if ϕ can be expressed as a twice totally delta-differentiable series, then the method can be extended to the general case (with non-constant graininess). This restriction is discussed below.

Lastly, there is an important application of dynamic equations to modeling predator-prey systems ([12]). The general model for such a system, where x and y represent the prey and predator populations, is given by the system

$$x^{\Delta}(t) = xf(x, y, t) - b(t)$$

$$y^{\Delta}(t) = yg(x, y, t) - k(t).$$

In the application of this system, f and g are nonlinear functions, so that this is a nonlinear first order equation. As before, the determining equations are linear total dynamic equations.

For first order equations, the formulas for total derivatives given in [2] indicate that the power series method can be used. However, as we are using a continuous Taylor series, higher order total derivatives may not exist, and assuming that the total derivative of a polynomial exists essentially amounts to the assumption that σ and/or ρ are differentiable, as the terms involving higher powers of t must be twice differentiable (see [4]). Although this is not always the case, it is important to mention that in the above examples the assumption is usually satisfied at least on piecewise intervals. For example, the model in economics is considered on discrete time scales with variable spacings, where the differentiability condition holds. In the population modeling example, the periodic time scale is usually considered, so that the continuous differentiability assumption holds on piecewise intervals. A solution to such an equation would only be piecewise differentiable in the usual sense, but it would be time-scale differentiable everywhere. This is a potential difficulty of applying the method to high order equations, but it is possible that the ability to treat the function as differentiable everywhere in the language of time scales may help avoid some of the problems that arise from discontinuities or non-differentiable points. This might be a good topic for further research. (Of course, for first order equations the differentiability condition is not needed). Therefore, while the method developed is most useful for first order equations, it does have applications to higher order equations, particularly in situations which often occur in physical systems.

Lastly, there is an alternative method for solving the determining equations. Essentially, it consists of a simplified ansatz where the vector field is in a particular form. The form used in [10] could be generalized as $v = [\zeta(x)u^\Delta - \phi(u^\alpha)]\partial u$, where α is a jump operator. While it is not in general true that such a method gives the complete algebra, it does allow for easier and often exact calculation of solutions, and is described in detail for difference equations in [10], along with other methods of using a simplified ansatz. The method could be extended to time scales with the above ansatz (or one analogous to those used in [10]) and in some cases may be preferable to the power series method. This would be particularly useful in the case of non-differentiable graininess if the power series method cannot be used.

5 Conclusion

The principle result of this paper is a general deterministic algorithm for solving dynamic equations and systems on time scales based on Lie groups, which is most useful for first order equations, but applies to higher order equations as well. The main usefulness of this method comes from the fact that it combines the generality and applications of

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time scales with the continuous Lie symmetry method. This method is particularly useful for nonlinear equations since, similar to the continuous case, it reduces a complex problem to a simpler total differential equation which can then be more easily solved. Furthermore, as methods for finding exact or, if necessary, numerical solutions (with an error bound) were derived, the method can therefore be applied in the wide variety of situations where time scales arise. Of course, this also introduces several areas for further research. For example, although an explicit method for solving dynamic equations was given, a specific program for implementing this method on a computer algebra system would certainly be useful. Furthermore, the theory of integration of differential equations is a useful extension of the prolongation method in the continuous case, and it would be interesting to determine how this theory could be generalized to the method given above. Also, while the method derived can be used to solve higher order equations under restrictions which are satisfied in many applications, it would nonetheless be useful to fully generalize the method to such equations. Overall, the underlying method of Lie symmetries was derived in this paper, and areas for further research lie in the related topics which already exist in the continuous case, as well as extensions to the derived method.

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When Lies Matter: The Effect of Media Coverage of Misinformation on Public Opinion in the Health Care Reform Debate

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Abstract

Buzz about misinformation in the media is on the rise, and researchers have been fascinated by the spread of the “death panels” rumor in the health care reform debate. This study builds on contemporary research on misinformation with an experiment to determine the extent to which journalistic practices helped propagate misperceptions about health care reform. The study finds PolitiFact to be an effective tool for debunking misinformation, while coverage of policy facts as partisan differences of opinion (a frequent practice according to researchers) can dangerously direct citizens to form misinformation-influenced opinions about policies, like

repealing the health care reform law and determining the law to be unconstitutional in this study. This study found that, despite decreased misperceptions in politically knowledgeable and attentive citizens, partisanship (support for political party and support for a candidate) as well as interest in topics related to the misinformation led to higher rates of misperceptions. This study suggests journalists use non-partisan, fact-checking organizations to double-check their facts as well as presenting information that citizens will believe.

Introduction

The health care reform debate is a policy issue that has incited strong reactions in Americans across the political spectrum. In a time of increased public interest for such a complex policy issue, news organizations seemed unable to satisfy the public's desire for developing information. With growing lust for policy-specific news coverage of such a politically polarized issue, rumors and speculation become topics of discussion within the 24-hour news cycle and across the blogosphere so that the lines between factual news and rumors become blurred. When political elites make their way into the discussion on one side, their opponents defend the counterpoints, leaving citizens caught in the middle of a he-said, she-said debate over factual issues.

For those who believe that citizens use the information they receive from the news to make political decisions, this is a troubling point—are citizens basing their votes and their talks around the dinner table on lies? Do they violently oppose or stand behind legislation, and political parties, because of a belief in an untruth? Citizens do believe misinformation—nearly half of Republicans and 20% of Democrats believed the “death panel” claim in the month after the Sarah Palin Facebook post that ignited a whirlwind of media coverageⁱ.

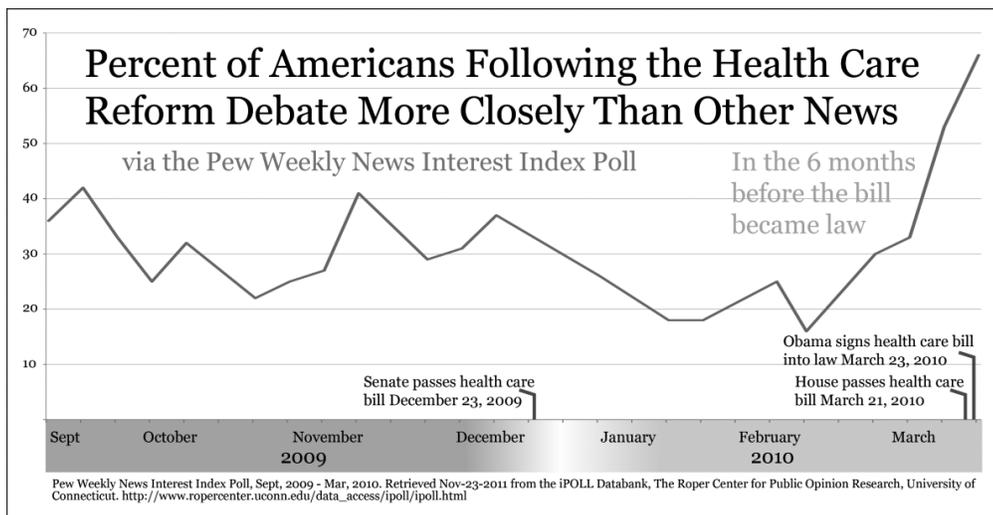
With all of the news on the issue, with Democrats and Republicans weighing in on either side, and with non-partisan fact-checkers striving to set the record straight, 1 in 3 Americans ended up believing “death panels” had a place in health care plan in August 2009. Did this affect their votes in the November 2010 election? Did it lead to the Republican swing in Congress or the dip in President Obama's approval rating? If so, news organizations could play a major role in affecting public belief of misinformation with the ways they cover these policy issues and the rumors surrounding them. This coverage could significantly affect what citizens learn from the developments they so eagerly seek—an audience of 42% of Americans had their eyes fixed on health care reform in the month after Palin's comments (See Figure 1)ⁱⁱ.

After reviewing American interest in health care reform and research on misinformation, I give an overview of my experiment, in which I measure the effectiveness of misinformation corrections. My results include the circumstances under which one

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Figure 1

At least 16% of Americans were most closely following health care reform in the time between Sarah Palin's "death panel" Facebook post and the point when the legislation became law. High points in the months leading up to Obama's signing the bill into law peaked around 42%, but as momentum built in March 2010, the majority of respondents had their eyes on health care reform.



believes misinformation and the way these misperceptions correlate with opinions about policies. I conclude this study with suggestions for journalists and fact-checkers concerning effective practices for correcting political misinformation.

The Health Care Reform Debate

The health care reform debate has captivated Americans in the last three years, remaining a constant in the swirl of news media and dinner table discussions. It is a polarizing topic that excites some and terrifies others, but whatever the stance, it seems the majority of Americans have an interest in seeing how health care reform turns out.

Pew Research polls found that Americans were often following the health care reform debate more closely than any other topic in the news (particularly in the months leading up to the bill's passage—see Figure 1)ⁱⁱⁱ. These polls suggest that neither swine flu nor the Tiger Woods sex scandal could pull Americans' attention completely away from health care reform. This data also shows that the debate had points where it completely dominated all other news with 2 out of 3 respondents saying they were focused on health care in the days after Obama signed the bill into law⁵.

Why are Americans captivated by health care reform? What about this policy issue made citizens stop and take notice? Neera Tanden, a former Obama health reform adviser, said it well in her keynote speech for the 2011 Texas Tribune Festival:

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Health care reform is different from other issues. Everyone has their own expertise on the health care system because we all experience it directly. That's not really the case with energy legislation or financial regulation or any other issues. Health care really touches people. And in a time where people are facing squeezed wages and people are worried about losing anything they have, the fear around health care reform really grew dramatically... (13:26)^{iv}

Health care is something everyone has some intimate experience with, from grappling with a family member's cancer, to taking children in for their first shots, to rushing to the emergency room—everyone feels health care because so often it is a matter of life and death. Tanden went on to tell a story about a woman whose daughter had cancer; the family's health insurance threatened to cut them off after having spent over \$1 million until the Affordable Care Act kicked in and removed those caps on spending. For reasons like this, the worry Americans have about health care translated to a worry about the legislation because of the implications for citizens' everyday lives—it is a financial, personal worry about keeping one's family healthy. Wrapped up in emotions, the legislation leaves citizens on the edge of their seats, wanting up-to-the-minute, continuing coverage of the health care reform debate.

When politicians see this increased interest they jump in and make a statement to connect themselves to the issue, creating more media and attention. In this situation, citizens' interest in politics and a particular policy interweaves with elites desire to be relevant in discussing issues of public concern to perpetuate media blitz surrounding a policy issue.

This insatiable curiosity led to speculation about just what the bill would do. However, the bill's notoriously large page count begged the question: how can anyone know for sure?—the length of the nearly two-thousand-page document^v was referenced as cause for concern and as a quandary for finding the truth. Speculation began to circulate in the blogosphere about potentially troubling aspects of the bill from forcing all citizens to purchase health insurance, to tax increases, to end of life counseling for the elderly. This speculation by bloggers and other citizens made its way into mainstream media where speculation was discussed by elites, which kept health care reform a hot topic in the news.

The highly publicized uncertainty surrounding health care reform and the interest it generated in citizens set up a perfect storm for propagating incorrect information about just what the legislation would do. The most notable of these, the “death panel” claim (pioneered by Betsy McCaughey in opposition to Bill Clinton's health care proposals, and reignited by Sarah Palin and Sen. Charles E Grassley in public opposition to Obamacare^{vi}) circulated widely, inspiring 20,900 articles via Google News since the beginning of Obama's presidency. Not only was it spread widely, but it was believed by a significant percentage of Americans: 30% from a Pew Research August 2009 Poll—47% of Republicans and 20% of Democrats believed the “death panel” claim was true based on hearing something about the legislation (Figure 2)^{vii}.

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The fact that the claim was able to catch on and was believed by 1 in 3 respondents shows that the circumstances of this situation make it an interesting one for examining public opinion and knowledge of policy-specific information. Because the public was interested in a policy issue with which they had low competence and no options for receiving enough information to suit their curiosities, these rumors were able to grow. A case study, on how misinformation of the health care reform debate was covered and affected citizen attitudes toward the legislation and political parties, will prove useful for understanding how citizens make political decisions regarding public policy issues and how coverage by journalists can affect public knowledge in instances of misinformation.

Misinformation

In a study examining the effect of misinformation surrounding American welfare policy, James Kuklinski (et al) states: “If facts are the currency of citizenship, then the American polity is in a chronically impecunious state.” in agreement with Delli Carpini, Keeter, Galston and others who assess political knowledge (791)^{viii}. We know that the media can strongly influence the public in terms of what citizens know and how they think about politics (Zaller, 1992; Delli Carpini & Keeter 1997). Delli Carpini and Keeter found that while Americans have a firm understanding of basic political structures, laws and US political history, all have significantly lower knowledge of public policies, especially those of social services—even the groups with the highest predispositions toward political knowledge (1997). This ignorance of public policy is troubling because research has found that people use these policy-specific facts to make political decisions (Gilens, 2001).

Kuklinski argues that as much as citizens are *un*informed, they may be more so *mis*informed and stubborn to hold on to their prior beliefs even when they are presented with corrections. This, he says, obviously builds barriers to properly educating citizens as well as building up public opinion based in counter-factuality, which could differ greatly from the opinion were it based in fact (792). Kuklinski also argues that as these misperceptions become more widely accepted, they assume a status of common knowledge, which makes them even more difficult to counter with the truth in civic education and information (793). These beliefs are often skewed in the direction of political leanings and prior assumptions, said Kuklinski (794) in agreement with Larry Bartels^{ix}.

Citizens do this to remain consistent in their attitudes, beliefs, and actions in attempts to manage cognitive dissonance. Leon Festinger coined the theory of cognitive dissonance: a phenomenon identifying the uneasiness one feels when faced with personal inconsistency^x. A citizen would act in accordance with his/her own beliefs to avoid self-contradiction because consistent people are generally held in higher esteem than those who flip-flop. This holds true in politics and everyday life; the attacks and caution surrounding Mitt Romney’s contradictions (like those, which the site MittRomneyFlipFlops.com is built around) are recent examples of society’s discomfort with inconsistency^{xi}. Once attitudes

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take hold, like a stance on a policy issue consistent with one's political party, citizens are more likely to side with their current beliefs when deciding what to believe (consciously or unconsciously). Kuklinski found just this; in his data, he found a correlation between beliefs and policy preferences (801)^{xiii}. Because of this, Kuklinski found that facts contrary to one's beliefs were ineffective at persuading because participants "either did not absorb them or did but failed to change their preferences accordingly" (803).

Determined to beat citizens' stubborn clinging misperceptions, Kuklinski ran one more study, this time explicitly correcting misperceptions once he had their attention. The study asked participants what they thought the welfare budget was and what it should be, and then presented the experimental group with the correct number, which was almost always lower than either their estimate or preferred percentage. Kuklinski found that such a bluntly presented correction was enough to correct participants' misperceptions:

Misinformed citizens, then, do not always remain oblivious to correct information. If it is presented in a way that "hits them between the eyes"—by drawing attention to its policy relevance and explicitly correcting misperceptions—such information can have a substantial effect. (805)^{xiii}

By explicitly presenting the contradiction in an inarguable way, citizens are able to correct misperceptions and/or take on beliefs based in truth. In the Kuklinski study, this worked even with those who were most opposed to welfare spending—those who believed its extent and cost were far beyond where they stood in actuality (806). Thus, to combat misinformation, citizens must be bluntly corrected, or "hit between the eyes" with the correct facts in order to be knocked out of their shortcuts of believing untruths, which lean with their political biases. Brendan Nyhan and Jason Reifler looked into correction strategies in the 2010 article *Why Corrections Fail: The Persistence of Political Misperceptions* and found that corrections failed to reduce misperceptions, and in some cases, news consumers actually strengthen their previously-held, incorrect beliefs when presented with a correction. These backfire effects were found to be strongest in the groups who believed a particular piece of misinformation most strongly (eg: a strong Republican who holds a misperception that fits with the party manifesto is likely to retain this belief and may be more resolved in it after seeing a correction), according to Nyhan's and Reifler's research^{xiv}.

The research project corrected misperceptions about weapons of mass destruction in Iraq, tax cuts, and stem cell research using short articles with an untrue quote (by George W. Bush about Iraq in the first instance) and then correcting it with a quote from another source (the Central Intelligence Agency, the Congressional Budget Office, and "experts," respectively). What may be missing in these corrections is a source who is perceived to be reputable, accountable and unconnected with the politician/the political machine: 1) The CIA is reputable, in that it is a government agency, but this connectedness may psychologically place it too near to the president (and thus politics), which would undercut

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its objectivity. The fact that the CIA is cited generally (and not a representative from the agency) leaves room to add to accountability. 2) The Congressional Budget Office is in the same boat as the CIA, in being too connected to politicians. 3) While “experts” carries a sense of trustworthiness and objectivity, unnamed experts are not accountable for their comments and thus have the possibility of being less reliable to news consumers. My study uses a non-biased, non-partisan source, PolitiFact, to correct claims by a politician. In using an objective group to combat misperceptions, participants are less likely to write off the corrections as just another politician or bureaucrat trying to spin the fact in his/her favor. Nyhan and Reifler also attempted to determine whether or not the source of the news organization affected the believability of the claim by interchanging The New York Times and FoxNews.com, but the researchers found no significant difference and suggested that the change was too subtle—from this, they speculated that a change in the source (from news organization, to correcting source) may change results. My study accounts for perceived bias in news organizations by using a wire service, Reuters which doesn’t carry perceptions of strong partisan ideologies with it.

Nyhan continued to study misperception in *Why the “Death Panel” Myth Wouldn’t Die: Misinformation in the Health Care Reform Debate* in following Betsy McCaughey’s creation and propagation of the myth through the Clinton and Obama health care reform plans^{xv}. The analysis found that Republicans were generally more likely to believe the false claim, with Republicans and Independents believing the “death panel” myth at a greater rate when they were confident in their understanding of the legislation. The former finding makes sense, as Republicans would be more likely to latch on to a fact supporting a position they already hold (one against health care reform bills); this fits with cognitive dissonance theory. It is an interesting point that those who felt they best understood the legislation were those who fell on two very different conclusions: “well informed” Republicans believed it at 84% with Independents about 20 points behind, while Democrats in the same position fell on the polar opposite end with 15% believing. Cognitive dissonance theory may be at work here as well so that those who have made up their minds about health care reform want to feel more resolved in their decision so that they believe they know as much as there is to know about the legislation. It will be interesting to see the extent to which this differs from political knowledge and interest findings from my study.

Also intrigued by the “death panel” claim, Matthew Schafer and Regina Lawrence looked at how widely misinformation was spread through the media in the health care reform debate in *Sarah Palin’s 2009 “Death Panel” claims: How the Media Handled Them, and Why That Matters*^{xvi}—the analysis of media coverage of the claim found that many journalists labeled “death panel” claims as false, with some not backing up their debunking with facts from the legislation or credible sources. Others still portrayed the claim as a difference of opinion by showing both sides. This ritual of he-said, she-said coverage is called *procedural objectivity* by the researchers. Journalists here are seeking to include both sides of the issue

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in attempts to remain objective—they position their reporting in the middle of a debate so that flak comes from both sides fitting with the reporter’s adage that ‘you know you’ve done a good job once everyone’s complaining.’

However, this obedience to objectivity irresponsibly gives validity to both sides in the argument—in this way, a gamut of scientific research on the existence of global warming on one side can be reduced to just an opinion when opposed with findings from fringe researchers that the phenomenon doesn’t exist. In cases of fact (or well tested theory), journalists do their readers a disservice by presenting both sides as an argument in procedural objectivity. It is even more the case in a policy issue like the health care reform debate: values and priorities of what to support can be argued, the preferred size and scope of government intervention through the legislation can be argued, but the facts of what the legislation provides for cannot. The question is, then, whether or not the Affordable Care Act provided for government-orchestrated death panels. The answer was no: death panels would not and do not exist. Schafer and Lawrence found that “between two-fifths and two-thirds of news stories in our sample treated ‘death panels’ as an open question” (18). My study will examine the rate at which citizens believe misinformation when exposed to coverage that employs procedural objectivity as opposed to coverage, which debunks a rumor with facts from a credible organization.

As gatekeepers and watchdogs, journalists have the job of adjudicating facts. In taking on this role, they are performing what Lawrence and Schafer call *substantive objectivity*—here reporters labeled the “death panel” claim false in 39% of stories (15). It is encouraging to see that a number of reporters covering the claim took steps to help readers understand the truth of the political debate, but a majority of these “false” labels were unsubstantiated: 83% of the stories gave no explanation about the provisions of the legislation^{xvii}. Telling citizens that something is false without telling them why is likely to prime citizens to side with their original biases—this approach doesn’t “hit them between the eyes.” It isn’t a strong enough correction as Kuklinski (et al.) and Nyahn & Reifler found in their studies, a correction has to be substantially strong to change misperceptions. Substantive objectivity seems like it could be the smack between the eyes citizens need to correct political misperceptions. This study will answer the “why?” after presenting a judgment about a piece of misinformation, so that corrections don’t leave room to readers to explain away the answers and remain resolved in their misperceptions.

PolitiFact and other fact-checking organizations, like FactCheck.org, serve this purpose by doing the research necessary to tell citizens the extent to which claims by politicians are true (or false) and why (or why not). This study will cite PolitiFact, a “nonpartisan fact-checking organization,” as a source in correcting misinformation to determine how effective this resource could be for journalists in getting the truth to their audiences. An effective, easy-to-cite tool for journalists can help to better inform American citizens so that they can form political opinions based in fact. Had more of the 30% of American

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“death panels” believers been “hit between the eyes” with the truth more often, the debate surrounding health care reform may have taken a different tone.

Research Questions

Does media coverage dissuade citizens from or encourage them to believe misinformation?

Can media consumers be deterred from believing misinformation if it’s debunked by a credible source? Can journalists employ a substantially strong correction to give citizens the “hit between the eyes” they need to correct their misperceptions? And is PolitiFact, as a non-partisan fact-checking organization, enough of a credible source to effectively inform citizens of the facts surrounding a policy issue?

Does believing misinformation affect a citizen’s support for the candidate propagating it, support for the party favored by the misinformation, intention to vote, and political knowledge?

What factors of civic engagement and political predisposition affect and are affected by a belief of misinformation? Are misinformed citizens more likely to vote for candidates in their party, and does a correlation in intent to vote and party preference only benefit the party favored by misinformation? In what ways do political engagement, news interest, and political knowledge relate to the extent to which citizens will believe misinformation? Ultimately, does misinformation have any effect on the political process, or do citizens ultimately ally with and believe what their party of preference suggests, leaving misinformation as just another fact to pelt at supporters?

With this study, I build upon current analyses of how misinformation is covered to shed light on the effects of misperceptions on public opinion, politics and political knowledge. Could the “death panel” claims and others surrounding the health care reform debate affect citizens’ expectations and actions surrounding the policy swaying their votes in a direction a misinformation-less debate wouldn’t have? My study will attempt link coverage of misinformation to political actions and attitudes to determine just how important the role of these untruths has been in this ongoing debate.

Findings could support the efforts of fact-checking organizations like Politifact and responsible coverage from journalists as guardians of the truth, who can effectively correct misinforming pundits. In this case, the results would put the impetus on journalists and responsible civic leaders to fend off misinformation and keep politicians accountable for the “facts” they disseminate.

Non-significant differences in politics and intentions between those who hold political misperceptions and those who don’t could suggest that Americans are not swayed by misinformation (or information in general) as much as they are by political party and social status showing an over-valuing of fact-checking in today’s media. These findings would argue that misinformation doesn’t play as strong a role in decision makers as PolitiFact and researchers had feared. This could free up journalists and researchers to refocus their efforts to best inform American news consumers.

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The Study

In examining the conditions under which citizens believe misinformation, I used a post-debate, campaign story to test for the effects of misinformation. The story is a typical, generic campaign update focusing mainly on the candidate's economic policy stances in the aftermath of a Republican debate. The story came from post-debate coverage on SunshineStateNews.com, an online news organization in Florida, which is self-proclaimed to be "the only news organization in Florida with an editorial board that believes free-market, lessgovernment solutions will prove successful in addressing the problems challenging our state." The Sunshine State story, focusing on Michelle Bachman's responses from the October 11, 2011 Bloomberg/Washington Post Republican Presidential Debate^{xx}, provided an appropriate scaffolding for a study of the different ways misinformation can be presented and corrected.

Instead of focusing the experiment around Bachman, whose media coverage provided me with the skeleton for this project as well as the primary piece of misinformation, I chose to focus on the now-and-then GOP frontrunner Mitt Romney because he seemed to be the candidate with the most name recognition for citizens paying less attention to the election cycle, likely due to residual notoriety from his 2008 presidential campaign. Also, Romney has consistently remained more popular than Bachmann throughout the campaign according to the Real Clear Politics Poll Average, likely because the outspoken congresswoman has made more controversial statements than the pandering former governor (Figure 3).

The Sunshine State article began by summing up Bachmann's popularity in the fall of 2011: "Fading in the polls at the national level and in Iowa, where she claimed a big victory in the Republican straw poll in Ames in August..." (this was removed in attributing the article to Romney)^{xx}. My Romney-ization of the article was fairly straightforward: using analogous identifiers, each "Bachmann" became a "Romney" and so-on so that the average citizen would likely be unable to notice that the article was written with a different subject (especially because economic policies are dense and difficult to distinguish between candidates from the quotes provided). Of the articles I considered for the scaffolding for my control article, the Sunshine State News article was one which focused on the most detached policies and stances (the economy, energy, foreign trade) and made no mention of hot-button issues (social issues, health care, immigration, war). Because this article was wrapped up in high-level policy talk, I felt it was an appropriate one on which I could overlay my persuasive message about an issue unrelated to the rest of the story. This became the text for the control article.

To make the article feel more natural, I included a photo of Romney, replacing one of Bachmann. I selected a photo that would be the least persuasive (one without too much shadowing on the Romney's face and without big gestures and facial expressions) so that the photo would not add any unintended meaning to the article. I selected a Reuters image

from the August 11, 2011 Iowa GOP/FOX News/Washington Examiner Debate because it fit the bill and was without news organization logos in the background (to stay ambiguous in case a participant saw or heard something from the referenced debate)^{xxi}.

In another attempt to make the article feel real without adding persuasive factors, I attributed the article to Reuters by placing their logo in the top right corner above the title, crediting Reuters with the picture, and attributing the story to Tim Ghianni, a freelance journalist who contributes to the news organization from Nashville. I chose Reuters so that participants wouldn't perceive a reporting bias because of a particular news organization (like The New York Times vs FoxNews.com in Nyhan's research). Reuters, as a newswire-type organization, has less bias assigned to it while still being a name, which participants might recognize (from seeing it in their newspaper or online) and assign credibility as a result. The result: Figure 4 is the 408-word article control group participants were asked to read.

To this framework, I applied 3 variations, leaving me with:

- 1) A *control* with no mention of health care reform or natural gas/oil.
- 2) A story featuring *unchecked misinformation*: the control story with an added quote about government panels making health care decisions for older Americans and a quote about the extent of U.S. natural resources by Romney. Both quotes were labeled untrue by PolitiFact (false and mostly false, respectively).
- 3) A story featuring *substantive objectivity* in its coverage of misinformation: the control story with the added quotes from story 2 above and corrections from PolitiFact saying each quote is false (quoting the language from PolitiFact's website).
- 4) A story featuring *procedural objectivity* in its coverage of misinformation: the control story with added quotes from story 2 and corrections from story 3, but these corrections are instead attributed to White House Press Secretary Jay Carney.

The health care misinformation came from a Bachmann quote from the October 11, 2011 Bloomberg/Washington Post/WBIN-TV debate in Hanover, New Hampshire:

I think that senior citizens across the country have no idea that President Obama plans for Medicare to collapse, and instead everyone will be pushed into Obamacare,' Romney said. 'And just like Newt Gingrich said, the way that Obamacare runs, there's a board called IPAB. It's made up of 15 political appointees. These 15 political appointees will make all the major health care decisions for over 300 million Americans. I don't want 15 political appointees to make a health care decision for a beautiful, fragile 85- year-old woman who should be making her own decision. ^{xxii}

The quote exemplified the continued debate over the extent of government control over the health care system over a year after the Affordable Care Act passed. PolitiFact labeled the quote false on their Truth-O-Meter™ in an article they posted the next day (at 12:15AM)^{xxiii}. The article was distilled down with the help of a review of news organizations coverage of the Bachmann claim to the two-paragraph correction presented in the

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substantive objectivity and procedural objectivity stories. The only difference between the two instances was the source quoted for the correction: “PolitFact, a non-partisan fact-checking organization...” and “White House Press Secretary Jay Carney...” (the differences are highlighted in Figure 5).

After being presented with one of the four randomly assigned stories, all participants were asked the same questions about their partisanship, likelihood of voting for and support Romney or Obama, policy preferences, political knowledge and demographic information.

The survey was created and administered using Qualtrics survey software and participants were randomly assigned to one of the four stories using Qualtrics’ randomization methodology. The internet-based study took participants about 15 minutes to complete.

Results

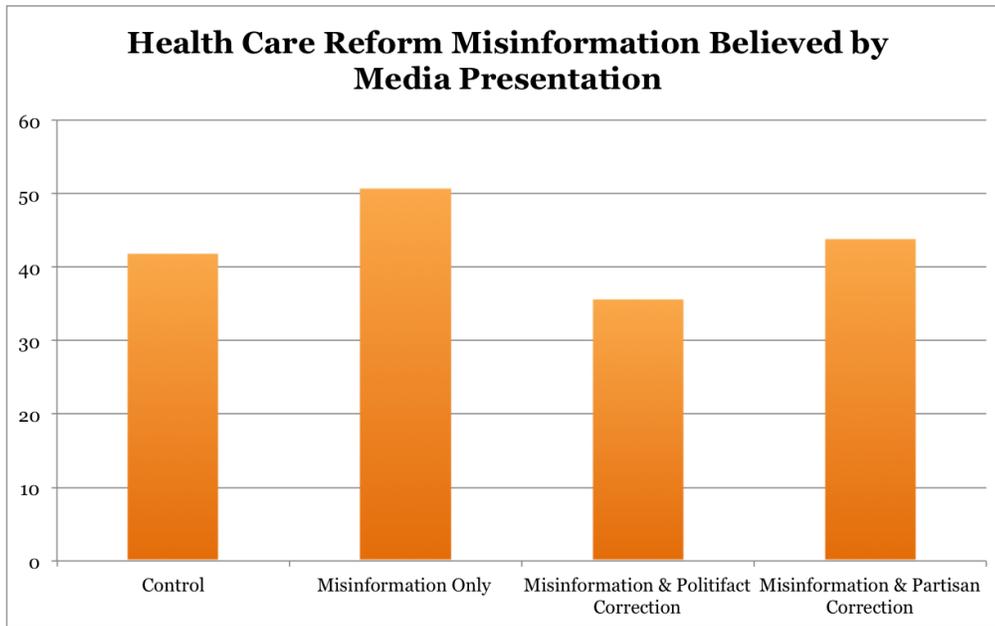
The survey was administered to undergraduates for extra credit in six classes between February 19 and March 9, 2012. The final count was 744 students from introductory government classes, journalism classes and a communication studies class (out of 826 who started the survey, a 90.1% completion rate).

On the central question of this study, there was a significant relationship between participants’ experimental groups and the rate at which they believed the misinformation at the heart of the Bachmann health care reform quote (See Figure 7). In a crosstabulation of the randomly-assigned experimental groups and answers to the True/False question, participants believed the health care reform misinformation at the following rates: Control group: 42%; Misinformation Only group: 50.8%; Misinformation & Politifact Correction group: 35.8%; Misinformation & Partisan Correction group: 44%; the χ^2 test is significant ($\chi^2(3, N=744) = 8.522, p < .05$).

Covariates (significant χ^2 tests, $p < .05$) with believing the Bachmann claim were self-reported political attentiveness: higher zeal for politics and news correlated with decreased belief in misinformation (See Figure 8); scores on my 7-question political knowledge test: higher scores correlated with decreased misinformation belief (See Figure 9); approval of the job Republicans have done in Congress in the last 2 years: increased support of Republicans correlated with an increase in believed misinformation (The χ^2 test is very significant; $\chi^2(4, N=744) = 15.050, p < .01$), but there was no significant relationship between the same question of Democrats (See Figure 10); and participants’ identification as Republicans: Republican identification correlated with increased misinformation belief (See Figure 11). The extent to which participants said they would vote for Romney if he became the party nominee was slightly related to misinformation belief: a likely vote for Romney correlated slightly (The χ^2 test is slightly significant; $\chi^2(1, N=742) = 3.323, p < .10$) with an increase in misinformation belief (See Figure 12). The issue participants said would affect their vote in November 2012 was also slightly related (The χ^2 test is slightly significant; $\chi^2(5, N=739) = 9.670, p < .10$) to misinformation belief: increased emphasis on health care correlated with

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Figure 7 **Percentage of Participants Who Believed Health Care Misinformation by Group**
 From a crosstabulation of experimental groups, participants answered “True” to a question stating that the Affordable Care Act allowed the government to dictate care for patients in the following breakdown: Control group: 42%; Misinformation Only group: 50.8%; Misinformation & Politifact group: 35.8%; Misinformation & Partisan group: 44%. The line presented is a baseline of the control group’s unprimed rate of believing the misinformation.



the highest belief of health care reform misinformation, while a focus on social issues correlated with the lowest misinformation belief (See Figure 13).

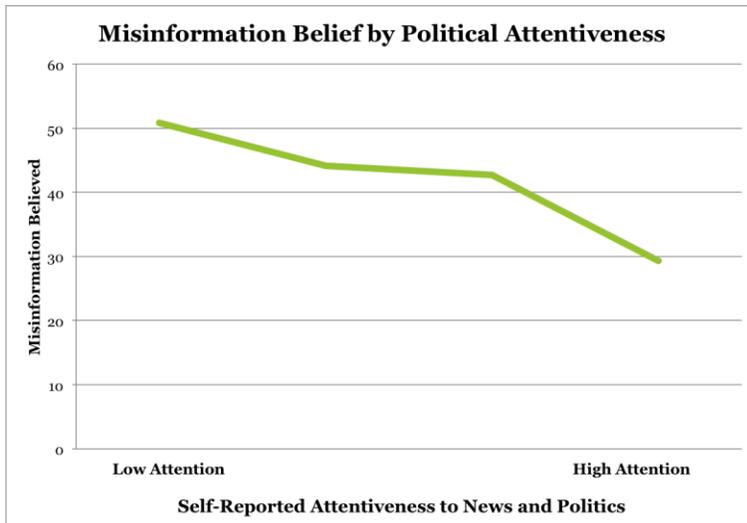
There was no correlation between belief of misinformation and voting history, intention to vote, age, education, race, ethnicity, donating to Romney’s campaign and approval of Congressional Democrats work in the last two years. Age, race and ethnicity were equally distributed across experimental groups by Qualtrics’ randomization and were largely equal across misinformation belief. Because the sample contained almost exclusively undergraduate students, this study may not be a good representation of the effects of misinformation with respect to education (as they are homogenous across the sample), voting (as many cited in comments that they were unable to vote in previous elections and the demographic has a generally depressed voter turnout) and campaign donation (as college students are unlikely to have disposable income for a donation, and because of depressed voter turnout, they are a smaller pool for funds than other age groups).

Believing health care reform misinformation also correlated with opinions about how the policy fits within the US system. On a question of whether or not participants believed the Affordable Care Act to be unconstitutional, there was a positive correlation between believing the claim and answering that the policy violates the constitution: 38.6% of those

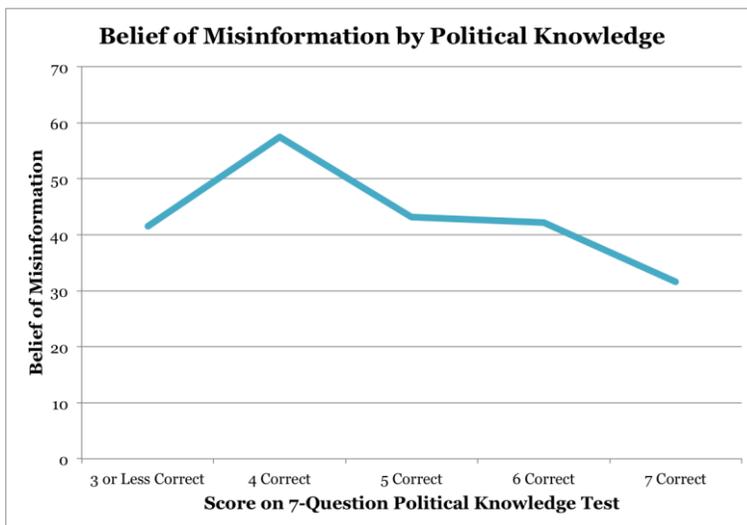
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Figure 8**Believing Misinformation by Political Attentiveness**

From a crosstab of the rate of health care misinformation belief with self-reported interest in news and politics, answers were: Hardly at all: 50.8%; Only now and then: 42.7%; Some of the time: 44.1%; All or most of the time 29.3%. The χ^2 test is significant ($\chi^2(3, N=739) = 9.612, p < .05$).

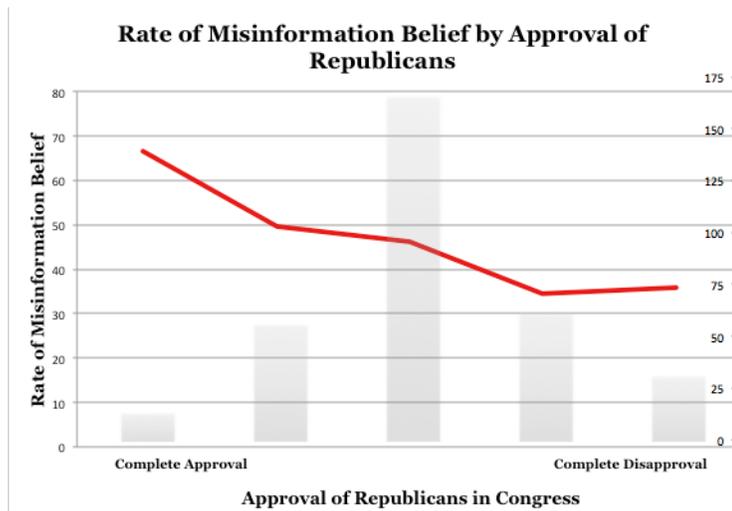
**Figure 9****Believing Misinformation by Political Knowledge**

From a crosstab of health care misinformation belief with a political knowledge test, participants fell along a logical trend (higher scores correlated with lower belief): 3 or less correct: 41.5%, 4: 57.5%, 6: 42.2%; 7: 31.6%. The χ^2 test is significant ($\chi^2(4, N=739) = 11.044, p < .05$).

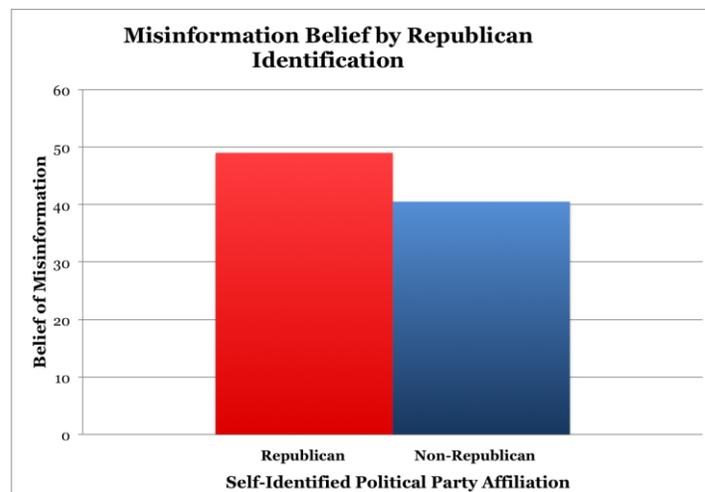


Believing Misinformation by Approval of Republicans in Congress**Figure 10**

From a crosstab of the rate of health care misinformation belief with of Republican legislators, the trend was from 66.7% belief with those who completely approved to 36% with those who completely disapproved. The χ^2 test is very significant ($\chi^2(4, N=744) = 15.050, p < .01$). Superimposed is the frequency of these responses.

**Believing Misinformation by Republican Party Identification****Figure 11**

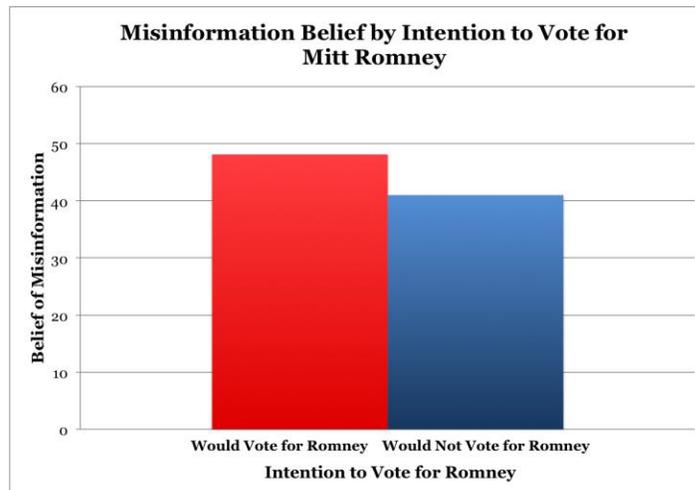
From a crosstab of the rate of health care misinformation belief with party identification, the breakdown was: Republican (Strong and Moderate): 49.0%; Non-Republican (Strong and Moderate Democrat, Independent) 40.5%. The χ^2 test is significant ($\chi^2(1, N=740) = 4.763, p < .05$).



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Figure 12**Believing Misinformation by Intention to Vote for Mitt Romney**

From a crosstab of the rate of health care misinformation belief with the likelihood of voting for Romney if he became the nominee, the breakdown was: Vote for Romney (With Enthusiasm, With Hesitation): 48.1%; No Vote for Romney (for Obama with enthusiasm and hesitation, undecided/no vote) 41.0%. The χ^2 test is slightly significant ($\chi^2(1, N=742) = 3.323, p < .10$).

**Figure 13****Believing Misinformation by the Most Important Issue Affecting Participants' Votes**

From a crosstab of the rate of health care misinformation belief with the which would most affect participants vote in 2012, Health Care was the issue that correlated with the highest belief (at 56.5%), while Social Issues correlated with the lowest (at 33.0%). The χ^2 test is slightly significant ($\chi^2(5, N=739) = 9.670, p < .10$).

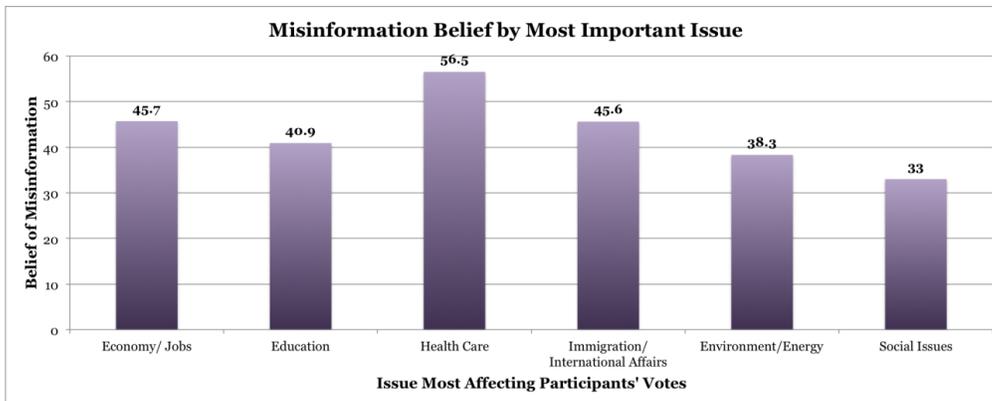


Figure 14 **Percentage of Participants Saying the Affordable Care Act is Unconstitutional by Media Presentation and Partisan Identification**
 From a crosstab of experimental group with partisan identification and answers that the Affordable Care Act is unconstitutional, rates of “unconstitutional” answers for Democrats and Republicans followed nearly-linear relationships as they descend down the table (and in checks to the claim’s validity), while Independents were relatively unswayed by PolitiFact and the misinformation presented alone, as opposed to Independents’ 19.2% jump in “unconstitutional” answers when the coverage presented a difference of opinion between Romney and the White House. The χ^2 test is very significant ($\chi^2(2, N=737) = 118.805, p<.001$).

Experimental Group	Democrats	Independents	Republicans
Control	10.7%	26.5%	50.0%
PolitiFact Correction	8.2%	28.9%	52.6%
Partisan Correction	16.9%	45.7%	60.0%
Unchecked Misinformation	20.3%	29.8%	69.8%

who called the policy unconstitutional believed the Bachmann claim versus the 29.2% who didn’t believe the claim (The χ^2 test is very significant; $\chi^2(1, N=737) = 7.160, p<.01$).

Sentiments on whether or not the policy is unconstitutional were significantly influenced by the presentation of misinformation in this study, and under these presentation differences, participants reacted very differently based on their partisanship (The χ^2 test is very significant; $\chi^2(2, N=737) = 118.805, p<.001$): Democrats and Republicans reacted with linear relationships to the increase in validity of the claim (from unshown, to shown and corrected, to shown and debated, to shown alone) with Democrats adding 9.6% to the unconstitutional column from the control to misinformation-only presentations, while Republicans added 19.8% to the same column (See Figure 14). Independents reacted differently: they were relatively unswayed from the control group by PolitiFact and Misinformation-only presentations, with variance within 4% from the control group in both cases; however, the partisan debate coverage led to a 19.2% spike in Independents saying the policy was unconstitutional (Independents were fairly equally distributed by Qualtrics randomization across the four experimental groups). PolitiFact had relatively little pull in the question of constitutionality, with less-than-3% variations from the control group across partisan ideologies.

Believing the health care claim also led to a stance on the policy that citizens could more directly affect with their votes: there was also a positive correlation between believing the misinformation and thinking Congress should repeal it. Participants who believed the health care misinformation said that legislators should work to completely repeal or change parts of the current law 74.2% of the time compared those not believing the misinformation, 67.4% of who believed it should be repealed; the χ^2 test is significant ($\chi^2(1, N=742) = 4.091, p<.05$).

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A desire to have the legislation repealed was significantly affected by participants' partisanship and the experimental article they were confronted with as well: a mention of the claim, be it debunked, debated or not, was enough to increase participants' desire to see the legislation changed, with increases by 10%+ in Democrats and Independents and 5%+ in Republicans from their dispositions in control conditions (Each group believed certain parts of the law should be changed at 50%+; only 6 Democrats said the law should be completely repealed, while only 13 Republicans said the law should stand, out of 739 participants—the χ^2 test is very significant: χ^2 (4, N=739) = 178.213, $p < .001$). Every Republican who saw the Carney correction believed that the law should have been changed or repealed along with the highest percentages of Independents and Democrats of any experimental group; the χ^2 test is very significant (χ^2 (2, N=739) = 117.138, $p < .001$). While Democrats generally answered similarly after seeing the quote and Republicans spanned the highest 10%, Independents were much more affected by the partisan debate and unchecked misinformation (representing a 22.1% and 20.4% jump from the control group respectively) than they were by the PolitiFact correction (a 10.5% jump)—See Figure 15.

Discussion

This study has determined that presentation matters when it comes to misinformation claims: by reporting the claim on its own (in a debate recap or from a press conference or other event where journalists may be unaware that the claim isn't entirely factual), journalists can assist the politicians cause by spreading the misinformation; by showing both sides of the "debate" in a partisan he-said, she-said presentation, journalists maintain and slightly increase belief of the misinformation; but by checking the misinformation, by "hitting citizens between the eyes" with a reputable, non-partisan source, journalists can actually correct misinformed beliefs in some citizens. And while the politically knowledgeable and attentive citizen is swayed less easily, the majority of Americans aren't, and don't desire to be, policy wonks, so the findings from this study that identification, either with the political party and candidate or with the issue, can increase a citizen's propensity to be misinformed are troubling.

These findings about misinformation reception would be less troubling were citizens not using it to influence their feelings about policy issues; however, because this study finds that, concerning the topical issues of repealing the law and making decisions about constitutionality, there is a significant connection between being misinformed and holding political beliefs in line with that misinformation, there is cause for concern. The fact that reporting style affects these sentiments, even outside of partisan predispositions, begs a criticism of journalism techniques: if, in the two-fifths to two-thirds of stories about "death panels" identified by Lawrence and Schafer^{xxiv} using procedural objectivity, readers reacted the way participants to this study did by taking on a belief supporting those misconceptions, then American sentiments toward health care reform could be very well based in lies.

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Figure 15**Percentage of Participants Saying Congress Should Repeal All or Part of the Affordable Care Act by Media Presentation and Partisan Identification**

From a crosstab of experimental group with partisan identification and answers that the Affordable Care Act should be fully or partially repealed, all participants' tendency toward repealing the law jumped by at least 10% at the mention of the misinformation, but the partisan presentation where Romney's claim was disputed by the White House was the highest among participants of all partisan leanings. The χ^2 test is very significant ($\chi^2(2, N=739) = 117.138, p < .001$).

Experimental Group	Democrats	Independents	Republicans
Control	44.0%	56.2%	88.5%
PolitiFact Correction	54.1%	66.7%	96.5%
Partisan Correction	56.0%	78.3%	100.0%
Unchecked Misinformation	54.4%	76.6%	93.7%

It is interesting that that the common practice of procedural objectivity incites a greater doubt in public policies, yielding the highest number of participants, across partisan ideologies, who believed all or part of the Affordable Care Act should be repealed. And it is particularly interesting that independents were so affected by this he-said, she-said presentation in terms of whether or not they believed the legislation is unconstitutional: with a 53.4% leg up on any other media presentation's sway of independents, it seems misinformation can be a powerful tool for swaying citizens opinions.

Conclusion

So what do we do to combat opinion swings by a misinformed citizenry? Stop misinforming them. This study has proved that we have effective measures for combatting some misinformation in our arsenal. With the exception of those covering a debate live or online and reporters putting together a quick summary of events, PolitiFact is testing and compiling the information necessary to adequately debunk misinformation claims in the hours after they are made (the examples used in this study were corrected by PolitiFact by the midnight after the debate), so there are options for journalists to inform citizens without risking misinforming them.

What must journalists do? Follow PolitiFact on Twitter, bookmark their website, or at the very least, check to see if the story being written has any contrary-to-fact statements inadequately corrected (by dropping in on the website of PolitiFact or another fact-checking service). Doing so with the "death panel" claim could have significantly restructured the debate about health care reform, and continuing to do so now as these claims continue to circle the political sphere, could resituate the conversation about the Affordable Care Act/Obamacare in a productive realm of fact rather than a flurry of misinformation.

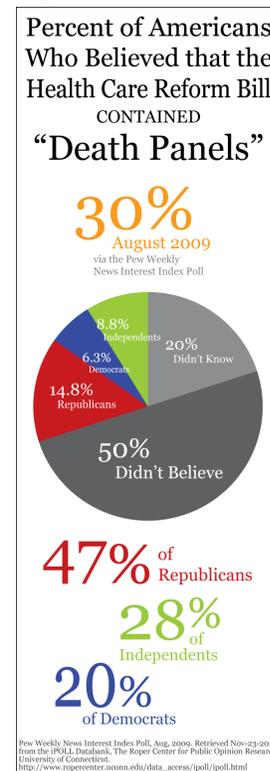
And what can PolitiFact do? Maintain credibility. A major reason for the success of

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PolitiFact corrections is the organizations’ commitment to objectivity in spite of bickering in the political realm. But fights over Politicians’ misused words may bring fact-checkers to that level. It is important to vet facts; and after investing resources and personnel into finding out whether a politician’s claim is true, publishing a judgment about the claim—true or false—is a good way for PolitiFact to show its objectivity in making judgments. But the organization may rethink their classification system for truths and falsehoods to condemn outright lies (and generate media coverage while doing it), while remaining lenient on smaller missteps so that the big lies stand out. This would make corrections more reliable and easier for citizens to stomach because of the organization’s air of fairness.

It’s intriguing how easily misinformation can flow through the mediasphere and be believed by citizens. It’s troubling that holding misinformed beliefs, from procedural objectivity, translates to policy stances that citizens wouldn’t have if they had been exposed to a substantively objective story. And it’s frustrating that the same correcting information given by a politician and fact-checker yields such different reactions from citizens. But we do have ways to correct political misperceptions, and we do have organizations that are already fighting to inject truth into our political debates. If PolitiFact and other fact-checkers uphold trustworthy standards for true and false in political debates, and journalists seek credible sources to correct misinformation, we may soon reach a point where politicians dread the title Liar of the Year and strive to get their facts right in advocating for issues.

Figure 2



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Figure 4 | **The Experiment, Part 1: Health Care Reform Misinformation****Taking Aim at Obama, Romney Explains Plan to Raise U.S. Employment**

Reuters

By Tim Ghianni

Former Massachusetts Governor Mitt Romney looked to get his campaign for the GOP presidential nomination on track as he explained his jobs and economic plans on Tuesday -- and bashed President Barack Obama's economic record.

"It's evident that the current trajectory of our country is simply not sustainable and President Obama lacks the understanding of how to return to a position of economic prominence in the world," Romney said in a statement released by his team on Tuesday. "My blueprint will create an environment which will create real jobs here at home, and return America to a position of economic prominence in the world."

Romney called for cutting the size and scope of the federal government and for lower taxes.

"We must decrease government salaries to bring them in line with their private-sector counterparts, and we must decrease the number of government employees. Overspending by the government hurts job creation by devaluing the dollar and stealing capital from the private sector."

Romney specifically singled out the alternative minimum tax and the death tax for elimination.

Romney also promised to fight against federal regulations, including those from the federal Environmental Protection Agency he maintained were hurting the economy, and called for repeal of the Dodd-Frank Act. Romney also called for more energy exploration, arguing that it could help give a boost to the American economy.

"This could create 1.4 million jobs, bringing \$800 billion of new revenue into the U.S. Treasury, and increasing domestic energy supplies by 50 percent," Romney insisted. "The price of energy has a direct impact on nearly every facet of our lives. We have to abandon the parochial and political energy policies of the past and install a comprehensive energy plan that not only reduces our reliance on unfriendly foreign regimes, but also creates millions of American jobs and generates increased tax revenues.

"According to the Congressional Research Service, the U.S. has more energy potential than any other country in the world," Romney added. "We should use that potential. It is a better policy to create American jobs and explore in an environmentally-sound way, than to rely on foreign dictators who give little regard to the environment."

Romney also promised to fight for free trade and offered harsh words for Obama's handling of agreements with Colombia, Panama and South Korea, which were finally released to Congress earlier this month after years of political negotiations. The former governor also called for increased manufacturing and technological education.

Jordan Humphreys

Figure 5 | *The Experiment, Part 1: Health Care Reform Misinformation*



Taking Aim at Obama, Romney Explains Plan to Raise U.S. Employment



Politifact-Checked: Substantive Objectivity

... He also called for removal of unnecessary government jobs and regulations such as those contained in the Obama Administration's federal health care law. The former governor added that the new health care law infringes on the free market and the ability of Americans to make decisions on how to spend money on their health, especially older Americans on Medicare.

"I think that senior citizens across the country have no idea that President Obama plans for Medicare to collapse, and instead everyone will be pushed into Obamacare," Romney said. "And just like Newt Gingrich said, the way that Obamacare runs, there's a board called IPAB. It's made up of 15 political appointees. These 15 political appointees will make all the major health care decisions for over 300 million Americans. I don't want 15 political appointees to make a health care decision for a beautiful, fragile 85-year-old woman who should be making her own decision."

Politifact, a non-partisan fact-checking organization of the St. Petersburg Times, said Romney's comments give the impression that the Independent Payment Advisory Board (created by the Affordable Care Act) makes decisions on individual cases. "We looked at the claim that the board decides 'whether you get care, such as continuing on dialysis or cancer chemotherapy,' and it does not." **Politifact labeled the claim as false on Wednesday.**

Although the Affordable Care Act did create a panel made up of 15 political appointees, called the Independent Payment Advisory Board, it has nothing to do with private medical decisions between patients and doctors. The board will only look at ways to limit Medicare spending and may make recommendations to Congress, which Congress may alter or block.

Partisan He-Said, She-Said: Procedural Objectivity

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White House Press Secretary Jay Carney rebuked Romney's comments, saying they give the impression that the Independent Payment Advisory Board (created by the Affordable Care Act) makes decisions on individual cases. "We looked at the claim that the board decides 'whether you get care, such as continuing on dialysis or cancer chemotherapy,' and it does not," **he said Wednesday.**

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Coral competition in the Great Barrier Reef: The competitive nature of coral families, morphologies and sizes in reef flat areas around Lizard Island, Australia

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Abstract

Despite the widely replicated finding that coral competition is integral to coral reef community structure, few studies offer direct experimental evidence of which specific coral families, morphologies, and sizes continually win in competitive interactions with others. Much of the available evidence highlights correlations between acute and chronic disturbances affecting a coral reef's resilience and recovery. Although previous studies provide important information of environmental effects on coral reefs, it is also necessary to first examine the way in which different corals compete to better understand coral reef composition and competition techniques for future

conservation initiatives. This study examined the overall density of corals within different reef communities to determine 1) overall abundance and 2) the types of coral families in competition. Winners and losers of each competitive interaction were recorded with the goal of determining the type of competitive trends that exist in the reef, if any. The goal was to determine which family or families are thriving and which are being beaten out for space. Lizard Island, off the northeast coast of Australia, has a high diversity of hard coral and soft coral families. Soft coral is a dominator when it comes to growth rate, which in turn translates into a competitive advantage. This study's findings are supported by the Intermediate Disturbance Hypothesis, which holds that a reef's biodiversity depends on these competitive interactions as well as efficient recruitment and recovery periods in between natural disturbances (Connell, 1978). Three different mechanisms by which corals may compete with each other are listed along with a suggested ideal coralline structure for reef resilience. This study shows that reef systems that have experienced disturbance events have lower biodiversity than healthy reefs, thus providing a better understanding of coral-coral interactions and ultimately supporting research efforts directed towards coral reef restoration and conservation.

Introduction

Competition between coral families on Australia's Great Barrier Reef is a common ecological process that maintains coral reef diversity in marine ecosystems (Sale, 1977). Coral reefs are composed of calcareous debris left from coral skeletons and other organisms (Bennett et al., 1993). Most grow in shallow, sunlit waters between 30 degrees north and south of the equator, ultimately covering less than 1 percent of Earth's oceans (Hoegh-Guldberg and Dove 2008). Various coral morphologies allow for direct observation of the vast diversity found in reefs. These include, but are not limited to: soft, branching, tabular, digitate, encrusting, free-living, and massive forms (Talbot, 1984). Previous studies have shown that a substrate, the surface on which an organism lives, with high diversity creates an environment of intense competition for limited resources (Sale, 1977). These limited resources include food from plankton, sunlight, and hard substrate to allow for colonization. Larval recruits, or young individuals, have specialized organs that enhance their ability to select suitable sites for settlement (Maida, 1994). These suitable sites include areas of dead coral, hard substrate, or areas that corals of the same species have previously settled. Recruits that reside close together have the ability to grow large and compete for substrate, light, and nutrients with others in their proximity. Spatial competition for hard substrate is typically referred to as the most significant factor in controlling coral composition upon reefs when compared to the abundance of food and sunlight (Connell, 1978; Lang and Chornesky, 1990; Tanner, 1997). Determining which coral families, morphologies, and sizes are competitively dominant in a variety of locations will better explain reef compositions and aid in the conservation of reef biodiversity.

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Coral reefs are the rain forests of the ocean; these highly diverse ecosystems are delicate environments subject to surrounding environmental and climate fluctuations. The Intermediate Disturbance Hypothesis notes that high biodiversity in an unstable environment advances towards a more stable, low-diversity community if it is undisturbed for a long period of time (Connell, 1978). This trend supports the fact that the growth rates of different coral families and morphologies subsequently influence competitive interactions. For example, Acroporidae and soft corals have rapid growth rates, which cause them to compete more often than other families (Baird, 2000).

The competitiveness of coral families and morphologies in a variety of reef localities must be determined in order to better understand coral reef compositions as a whole. When analyzing the varying susceptibility of corals to other dominating families one must consider direct competitive interactions, resilience, and recruitment ability. Coral recruitment is noted as an ecological “bottleneck” in many reef systems, playing a part in determining resilience and repopulation of reef areas after disturbances (Reef Resilience, 2009). However, this study focuses on the direct competitive interactions that include overgrowth, direct competitive contact, and shadowing of another coral colony for better understanding of coral reef competition and makeup.

Methods

Observation and Data Collection

This experiment examined how competition among corals on the reef flats varies with density and substrate cover. We documented the families of corals that compete on a regular basis, and the families, morphologies, and sizes that dominate in cases of competition. Using the three specific competitive mechanisms listed above, we categorized and recorded coral competitions to quantify the coral families that are most susceptible to competition and which are most dominant. We made approximate measurements of both the dominating and subordinate coral sizes in each competitive interaction and subsequently performed a series of DAI tests to relate coral family domination to their mechanism of competition (Dai, 1993).

The first goal of our study was to document coral composition at each of the reef sites. Coral cover, density, and competition were all observed using density transects at five sites surrounding Lizard Island Research Station in North Queensland, Australia (14°40'44.13”S, 145°26'53.94”E). Our study was conducted at multiple reefs around Lizard Island, located off the northeast coast of Australia. Most of these reefs are patch reefs or part of Blue Lagoon, which is located just off the island’s coast, directly between Palfrey and South Islands. *Acropora*, *Pocillopora*, *Porites*, *Favites*, and *Goniastrea* species form encrusting or coralline morphologies and are common populations in each of these reefs (Talbot, 1984). The sites each have unique community composition and geographic structure.

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Figure 1

Aerial photograph of Lizard Island and the surrounding reef sites we sampled from. Lizard Island (top center), Palfrey Island (bottom left), South Island (bottom right), Bird Island (right center).



Site 1. Palfrey Island: moderate diversity levels of both hard and soft corals. The diversity of the hard corals present was evenly spread across the six families for which we recorded data, with especially large populations of Faviidae and Mussidae massive morphology corals.

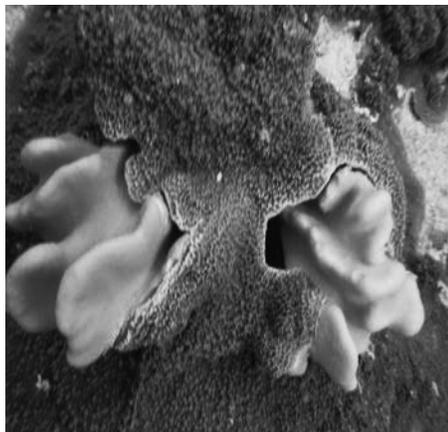
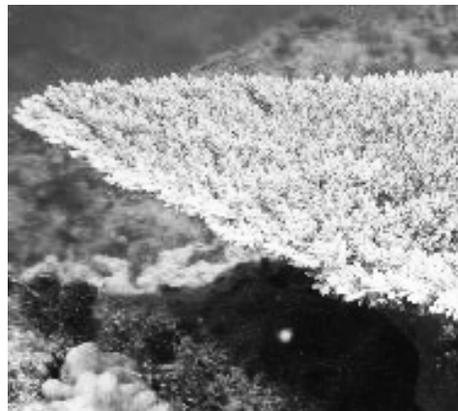
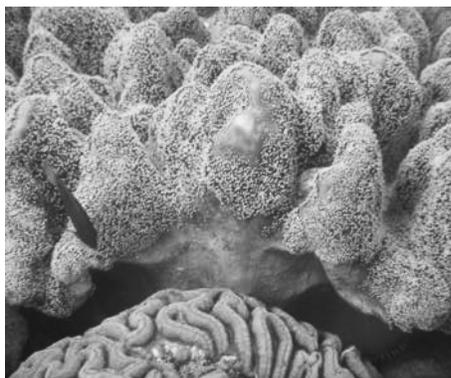
Site 2. Bird Island: moderate to high diversity and density with large populations of soft coral families and Poritidae massive morphology corals.

Site 3. South Island: high levels of hard coral cover and very low levels of soft corals. Acroporidae was the dominant hard coral species and was found primarily in tabular and branching morphologies.

Site 4. Clam Gardens: very high levels of soft corals and moderate to low levels of hard corals creating low biodiversity, but with a high coral cover and density. Poritidae was the dominant hard coral present.

Site 5. Lizard Head: moderate levels of both soft and hard coral present creating high biodiversity. There was an even distribution across all species of hard coral present in this reef, with frequent occurrences of coral recruits.

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Figure 2a | Overgrowth**Figure 2b** | Shadowing (Yasutake, 2007)**Figure 2c** | Direct contact

Observations were made within each site in the reef flat zone along four 15 meter transects using the stratified data point transect technique. If the transect intersected neighboring corals exhibiting competition at any point along the tape, the mode of competition between the two coral colonies was determined and recorded as one of three mechanisms: growing on top, shadowing, or direct contact (Figures 2a-2c) in which coral polyps containing toxic chemicals attack and kill encroaching polyps from another coral (Fearon and Cameron, 1996).

Once the mechanism of coral competition was confirmed, the coral colony that appeared to be dominating in the competition was noted based on presence of dying or dead tissues. Morphology and approximate size of both corals involved was also recorded. Morphologies were categorized as branching, encrusting, massive, tabular, free-living, or soft coral. All coral was measured at the greatest diameter across the top. The five size

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categories used as a measure of width included 5 to 15cm, 16 to 30cm, 31 to 60cm, 61 to 90cm, and 90+ cm. Following notation of competition, the coral density was measured by counting the number of coral families intersecting the transect line every half meter for a total of 30 data points. The transect lines served as our substrate composition replicates. The number of interactions between coral families that intercepted the lines served as our competition replicates. We accounted for seven different coral families, including Acroporidae, Pocilloporidae, Poritidae, Faviidae, Mussidae, Fungiidae and Soft Coral. Coral colonies whose classifications were unclear were photographed and recorded with their coinciding transect distance and taken back to the research station for correct family identification. Data collection was run through multiple statistical tests, including an ANOVA and a DAI analysis test. The DAI test was used when studying coral competition, including the families, morphologies, and the size of each coral involved in competition. It is conducted by tallying the number of times the family won or lost and using these numbers in the equation $[(\text{number of wins} - \text{number of loses}) / \text{total number of interactions}]$.

Results

Figure 3 illustrates the types of wave action and amount of disturbance to which each site is subjected. Northwest of Bird Island was located at the mouth of a channel exposed to a large amount of water flow. The water flow increases the amount of wave energy across the site, which in turn prevents hard coral from settling because it takes an extended amount of time for it to grow into a substantial coral. Soft coral, on the other hand, grows at a much faster rate and is able to settle and grow large in a much shorter time span despite disturbance from wave action.

In order to see what types of hard corals are being affected in each site and verify that the wave action hypothesis does not just apply to one family of hard coral, the percent coverage of six different hard coral families was also recorded (Figure 4).

This graph shows significant differences between coral covers of some families. Families showing significant differences include Acroporidae, having approximately a 40 percent difference in coverage between all five sites, and soft coral, which has an average 25 percent difference in coverage between all of the families. This is supported by the ANOVA test run for all of the families, in which Acroporidae percent cover ($F=92.801$, $df=4$, $p=0.000$) was found to be significant. Faviidae ($F=3.5882$, $df=4$, $p=0.03$) and soft coral ($F=4.6645$, $df=4$, $p=0.012$) were also found to be significant. Pocilloporidae ($F=1.222$, $df=4$, $p=0.343$), Poritidae ($F=0.3529$, $df=4$, $p=0.838$), Mussidae ($F=1$, $df=4$, $p=0.438$), Fungiidae ($F=0.75$, $df=4$, $p=0.573$), and the dead coral ($F=2.2729$, $df=4$, $p=0.11$) were found to have no significant differences in percent cover between sites. When looking at Acroporidae specifically across sites, we found that there was a significant difference when comparing site 1 vs. site 3, site 2 vs. site 3, site 3 vs. site 4, and site 3 vs. site 5. There was no significant difference when comparing Acroporidae across the other sites. Faviidae percent cover showed a significant difference

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Figure 3 | Total percent coral cover across all five sites

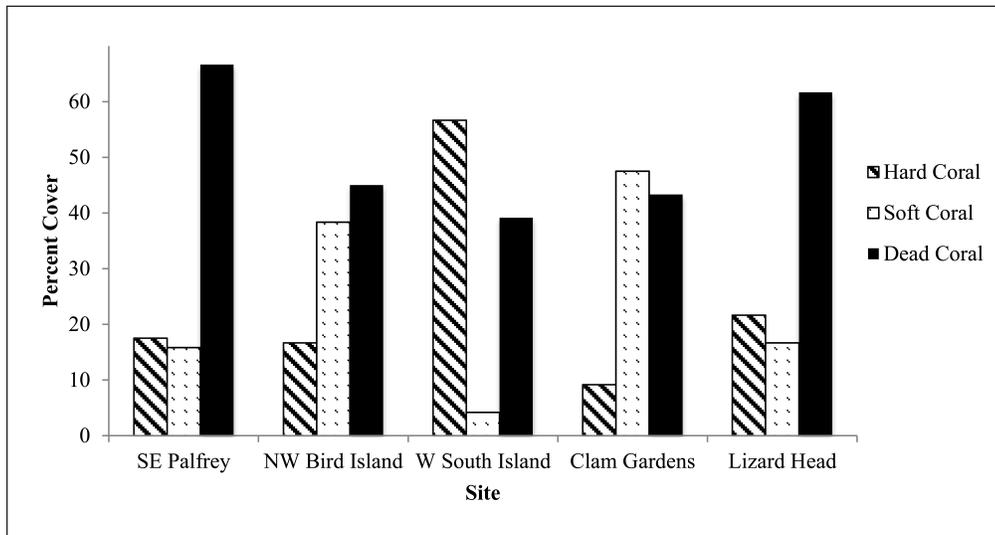
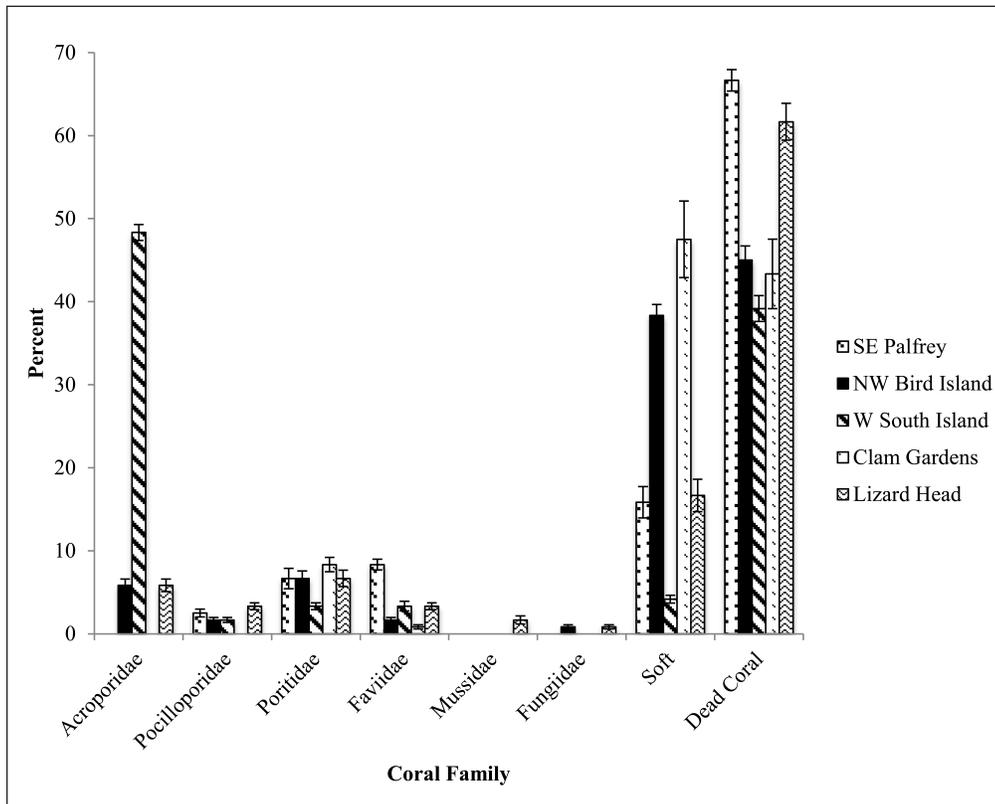


Figure 4 | Percentage of each coral family and all five sites



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Figure 5 | DAI Analysis of coral families at all five sites

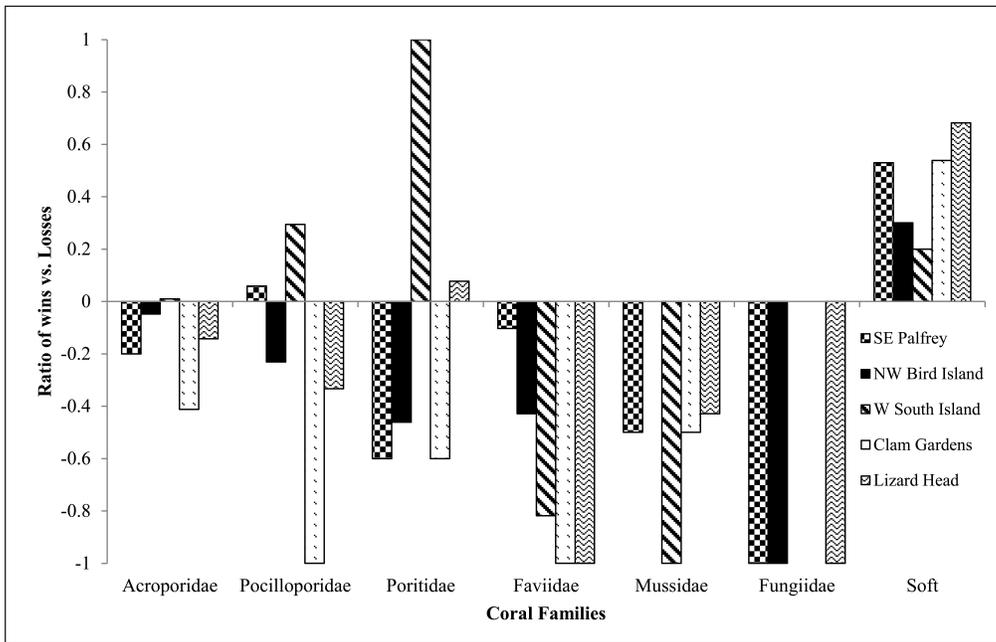
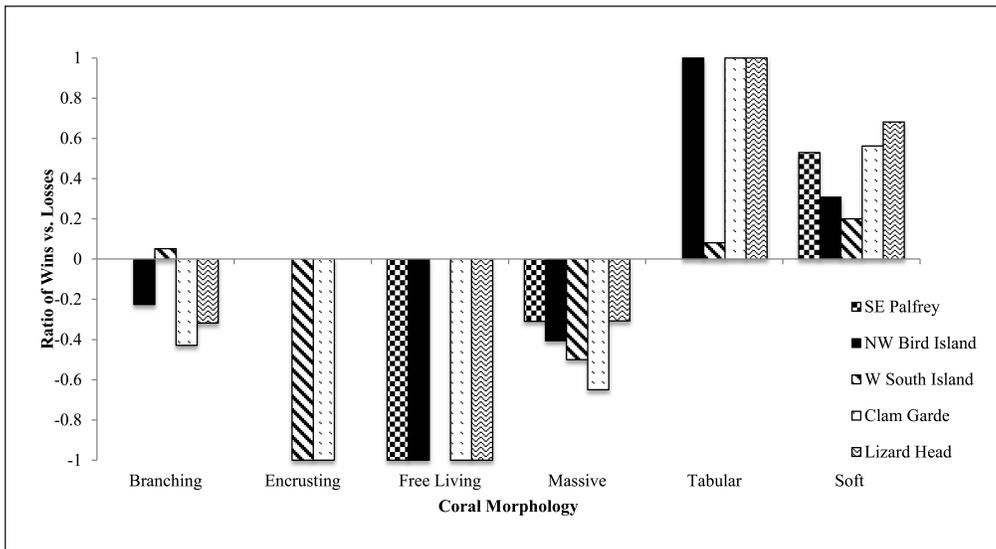


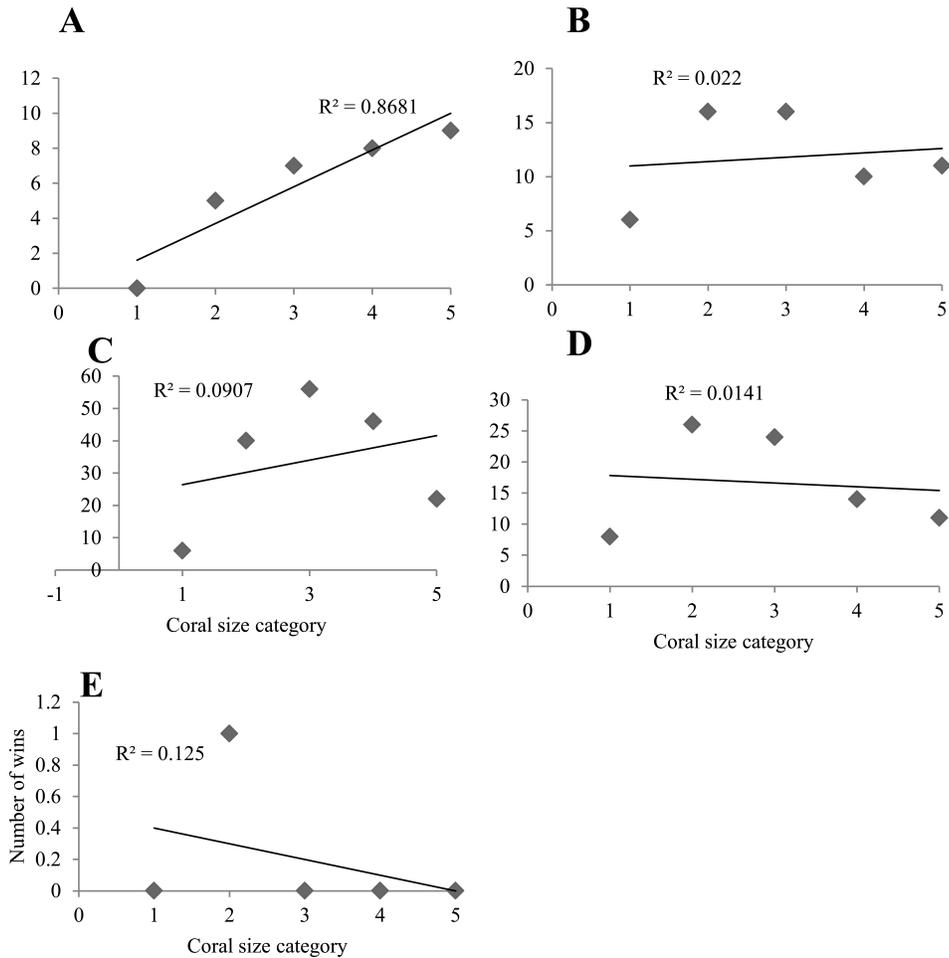
Figure 6 | DAI Analysis for morphologies at all five sites



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Figure 7

Regression analysis of the coral size category versus the number of times the morphology won. Sizes included 5-15cm (1), 16-30cm (2), 31-60cm (3), 61-90cm (4), 90+cm (5). The morphologies measured include tabular (A), massive (B), soft (C), branching (D), and encrusting (E).



when comparing site 1 vs. site 4. Soft coral also showed significant differences when looking at sites 3 vs. site 4. The families of Faviidae, Mussidae, Fungiidae, and Acroporidae lost all of the competitions in which they were involved (Figure 5). Some winning encounters occurred at the sites of Southeast Palfrey Island and West South Island by the Pocilloporidae family, and West South Island and Lizard Head by the Poritidae family. Soft coral is the only form of coral that experiences wins in all of their interactions at all of the reef sites.

All coral morphologies, except the tabular and soft morphologies, lost all of the competitions that they were involved in. Soft coral exhibited wins across all of the sites as did tabular, excluding site 1 (Southeast Palfrey Island), where there was no data for tabular coral.

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As size increased the data shows different trends (Figure 6). The only morphology that showed significant competitiveness was tabular coral ($t=4.4437$, $p=0.021$) when run through a regression analysis. Branching ($t=-0.2072$, $p=0.849$), massive ($t=0.2596$, $p=0.812$), soft ($t=0.547$, $p=0.622$), and encrusting ($t=-0.6547$, $p=0.559$) all showed no significance (Figure 6).

Results

Space within a reef is valuable; every coral must compete for space to settle and grow. The limitations on resources create fierce competition between corals. Each of the sites examined in this study exemplified this fierce competition, which occurs in three ways: overgrowing, shading, and direct combat. The diversity of hard, soft, and dead coral promotes competition (Figure 3). This diversity sets up each reef for competition.

Sufficient time between moderate disturbance regimes and recovery periods helps foster high-biodiversity in coral reef systems, as stated in the Intermediate Disturbance Hypothesis (Connell, 1978). Southeast Palfrey Island and West of South Island are more exposed to wave energy and high oceanic currents due to their location and distance from any form of buffering. Similarly, the reef sites at Lizard Head and just Northwest of Bird Island are also subject to similar wave energy that supplies a constant inflow of water and nutrients to a large lagoon or reef flat area. Conversely, the Clam Gardens site is in a calm bay protected from severe disturbances by physical barriers. Evidently, there exists a tradeoff between nutrient availability and protection from disturbance regimes such as cyclones or proximity to anthropogenic presence. Although soft coral density was high at Clam Gardens, more coral diversity was examined in the other four sites.

Although some diversity of hard coral was observed, soft coral dominated most of the reef sites sampled. This phenomenon could be attributed to the faster rate at which soft coral grows, or soft coral's resilience to disturbances that can decrease the percentage of branching or tabular corals (Adjeroud et al., 2002). This hypothesis is supported by the fact that soft coral is the only family of coral that consistently wins in competitive encounters. Tabular morphologies are also more successful than others, which is supported by the fact that tabular coral does not need much substrate to begin initial growth due to its tree-like structure (Figure 6). Through time, a tabular coral colony grows in size and strength and thus is more likely to shade competitors and dominate (Hughes, 1989). This advantage aids in withstanding intermediate disturbance zones, thus supporting the dominance of tabular morphologies closer to the edges of reef flat areas.

By using a regression analysis, we were able to support our hypotheses that larger tabular corals are more successful in competition (Figure 7A). The bigger the coral diameter, the older the coral is, suggesting that as tabular coral grows larger it becomes less susceptible to disturbances. The other morphologies revealed no statistical significance in this regard; size did not play a role in whether or not these coral won in competition.

This study shows that faster growing soft coral out-competes hard coral, dominating

many of the reefs around Lizard Island. This trend is important because it shows that, although there is still reef diversity in which competition and disturbances occur, soft coral is more prevalent in the reef. Bottleneck effects can reduce the size and diversity of coral reef populations. For the future of reefs everywhere, it is vital that diversity remains high so that a bottleneck effect does not occur. The geographic variety of Lizard Island's reefs provides a good sampling of reefs, most of which were dominated by soft coral. However, under all of the soft coral, the diversity of hard coral present was high. The presence of so much soft coral supports the fact that soft coral grows faster than hard coral. Disturbances play a major role in the recovery of a reef depending on the degree to which they affect the reef (Connell, 1997). Competition creates post-settlement diversity, as corals must compete for resources. For diversity to remain, hard corals must find a better way to adapt or compete more effectively with soft corals.

Limitations: This research did not include the ~350 species of coral found in the Great Barrier Reef for the sake of practicality and time constraint. Also, the sites used in this study do not necessarily represent the diversity of coral reef ecosystems present in the Great Barrier Reef, let alone other parts of the world. The three-week time-scale of this study limited our ability to collect enough data for significant pattern recognition. Due to reef variation around the world, over-representation of the reefs surrounding Lizard Island could bias our results and therefore require a longer term of study on a broader geographic scale. Information from this research can ultimately be combined with other databases to better understand coral ecology and recruitment, and how surrounding environmental conditions continually alter reef health. A great deal more research is needed to consider resource availability, coral recruitment patterns and other competitive interactions between coral species and challengers such as macro algae and predators. It would also be interesting to relate corals' structural morphology and resilience to determine trade-offs associated with growth strategies.

These findings are useful for the adaptive management in marine protected areas (Ban et al. 2011). Ultimately, this report suggests that a certain coral colony's morphology and size may not guarantee long-term survival due to ever-changing environmental conditions. Nevertheless, it is virtually impossible to test all of the significant factors that summarize coral reef resilience at one time, thus providing an opportunity for continuous revising of coral reef management techniques for restoration and conservation of these "rain forests of the ocean."

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Motivation and Design Considerations of a Compliant Mobile Base for Human-Centered Robots

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**Alan Shu-Ming Kwok and Dr. Luis Sentis,
Advising Professor**

Abstract

Robotics is a growing field that has received tremendous support and focus in recent years.

Backed by government and industry interests, robots now have the potential to move beyond traditional manufacturing setting into human-centered environments.

Therefore, safety emerges as one of the most fundamental requirements in designing Human-Centered Robots (HCRs). To attain HCRs with high mobility and safe behaviors, we designed and built a torque-controlled omni-directional mobile base, Trikey 2012, at the Human-Centered Robotics Lab in Mechanical Engineering

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Department. Our design focused on reducing backlash, friction, uneven load distribution, and difficult assembly steps to create a high performance compliant mobile base for HCRs.

Introduction

Robotics could be one of the most transformative revolutions of the 21st century. In 2008, the National Intelligence Council published a report [1] that included Service Robotics as being one of the six most disruptive civil technologies by 2025. The other areas included technologies within the fields of bioengineering, energy, and cloud connectivity. The report further suggested that the most favorable scenario, “Autonomous World,” is comprised of 1.) key advances in robotics R&D and 2.) strong support, funding, and regulation from government and industry. One of the end results would be “Robots [replacing] human workers in a number of skilled manufacturing roles, boosting the competitiveness of U.S.-based manufacturing.” This introductory section examines the extent and significance of robotics today, with further focus in HCRs.

Trends for Robotics Today

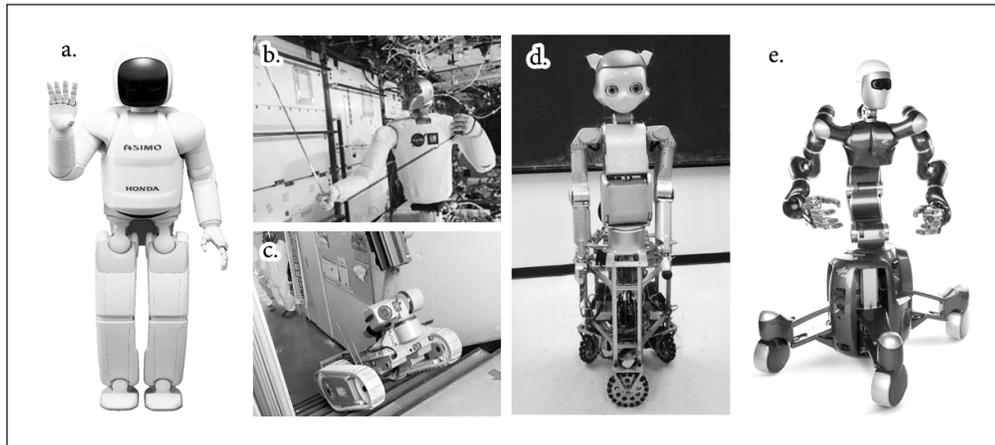
In June 2012, President Obama’s administration just announced the \$50 million National Robotics Initiative (NRI), led by National Science Foundation to “grantees around the country for the development and use of robots that cooperatively work with people and enhance individual human capabilities, performance and safety [2], [3].” The NRI is founded on reasoning that robotics can address a broad range of national needs from domestic, commercial, to military. Notably in 2011, NASA has already sent off Robonaut 2 to aid the International Space Station, becoming the first dexterous humanoid robot in space [4]. In all significance, these are merely small parts of the national support for robotic research.

From the private sectors, multi-billion corporations have become increasingly involved in intelligence machines. Honda has long been developing the world renowned Asimo [5], a 4’3” bipedal humanoid robot, since the year 2000. Microsoft Kinect, a 3D scanning system initially aimed for home entrainment, has revolutionized 3D mapping for robotics as well. In March, 2012, Amazon spent \$775 million on the acquisition of Kiva Systems, the creator of autonomous robots for shipping warehouses, to streamline shipping process [6]. Google, similarly, has several self-driving cars that have completed more than 300,000 miles of real world traffic as of August 2012 [7]. As a result, three U.S. states (Nevada, Florida, and California) have passed law to permit these autonomous cars on the road [8]. Along with multi-disciplinary corporations, application-focused robotic companies have also flourished. Intuitive Surgical, most known for its da Vinci surgical robot system, had USD \$2.18 billion revenue in 2012 [9]. iRobot, responsible for a wide range of products from home vacuum robot Roomba to military-focused PackBot, had USD \$435 million

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Figure 1

Various state-of-the-art robots: a.) Honda Asimo [5], b.) Robonaut 2 [4], c.) Packbot [12], d.) Dreamer [23], e.) Rollin' Justin [21].



revenue in 2012 [10]. Furthermore, research-focused companies such as Boston Dynamics and Willow Garage are pioneers that are driving these advances.

Besides consumer and U.S. administration support of robotic applications, we recently experienced the urgent need on an international level for robots to perform in disaster relief and humanitarian operations. On March 11, 2011, a magnitude 9.03 undersea earthquake impacted the shore of Japan and automatically shut down the nuclear reactors at Fukushima Nuclear Power Plant. Consequentially, the following tsunami flooded the emergency generators and crippled the cooling systems, which caused a catastrophic nuclear meltdown on par to the Chernobyl accident (both measured the maximum Level 7 on the International Nuclear Event Scale). To date, areas in Fukushima remain radioactive and unsafe for human operators. In December 2011, the Japanese government estimated that it would take the next 40 years to clean up and fully decommission the nuclear power plant [11]. From the initial aftermath, it was already apparent that reentering the partially damaged and heavily radioactive plant is crucial to retain control of the situation. However, it was also too dangerous for a timely and effectively human response. Eventually, teleoperated robots such as PackBot were used on-site and became essential tools for inspection; they provided important radiation recording in environments that would be lethal to humans [12]. These robots navigated through difficult terrains, such as debris-filled staircases, and highlighted the dire need for HCRs that can operate in human environments, along or in place of humans.

Human-Centered Robots (HCRs)

Historically, robotic applications have been dominated by industrial needs, constituting

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a global market of USD \$8.5 billion in 2012, mainly backed by automotive, electronics, and material manufacturing/handling [13]. However, today's position-controlled industrial arms are designed without compliance (defined technically as the inverse of stiffness, but also used interchangeably as the ability to sense, absorb, and react to force). This constrains them to operating only in factory environment and without the ability to engage in human interactions. However, as the technology advances, these robots now have the potential to spread beyond precision-based factories into human-centered settings such as homes, small businesses, and cities. Therefore, though HCRs can be either anthropomorphic or non-humanoid in design, they should all function with human safety as the most fundamental operating criteria. For example, there are multiple fields aiming to achieve safety, both preventively and reactively. Machine vision, motion planning, simulation, and sensor perception are all research areas that can identify and avoid dangerous situations preventively. In contrast, technologies such as low impedance actuators (motors with low stiffness) [14], soft flexible robots [15], or compliant control framework [16] can all damp and accommodate unexpected collisions.

Second to safety, HCRs must then have high mobility to navigate through common man-made terrains. A robot that could be easily obstructed by simple steps, gaps or curved surfaces is limited in its ability to perform mundane household or office tasks. While legged locomotion has advanced greatly, as evidence with BigDog [17] (an all terrain military quadruped) and other bipedal robots like Hubo [18] or Petman [19], wheeled platforms remain a proven alternative with high stability and energy efficiency. In conclusion, and regardless of means, effective and ideal HCRs should exhibit at least the following capabilities: safe interaction with human presence (planned or unplanned), mobility in rough terrain (urban setting), and precise manipulation in unconstrained environment (unlike industrial arms).

Goal of the Paper

Given the recap of support for robotics today, and the motivation for developing safe and efficient HCRs, the remainder of this paper presents the technical considerations used to design a compliant mobile base, followed by experimental results. With the goal to achieve safety in a reactive manner, Trikey 2012 is a wheeled mobile base with compliance as its primary design parameter. Furthermore, we focused on mechanical performance such as reducing backlash, friction, uneven load distribution, and difficult assembly steps to achieve compliant response. These considerations all have implications and applications to general engineering, especially force-sensing mechanical systems.

Design

The Trikey project began as an introductory design project at a local high school in 2010. Under the guidance of our laboratory, the team built the first version with a wooden

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frame and a general outline for parts placement. Subsequently led by graduate students Somudro Gupta and Pius Wong, four iterations eventually integrated electronics (Meka Robotics LLC), torque sensors (Sensor Developments), motors (Maxon Motor), and all other essentials into Trikey-V. Though operational, it suffered backlash and misalignments in the drive train, particularly from the inefficient miter gears and ill-designed frame assembly. Trikey 2012, as discussed in the scope of this paper, is a complete mechanical redesign during the summer of 2012. It consisted of designing in computer-aided design (CAD) software, sourcing components, machining, assembling, and testing. Therefore, the decisions and considerations we here forth discuss had the benefit of drawing on and comparing to previous designs and underperformance.

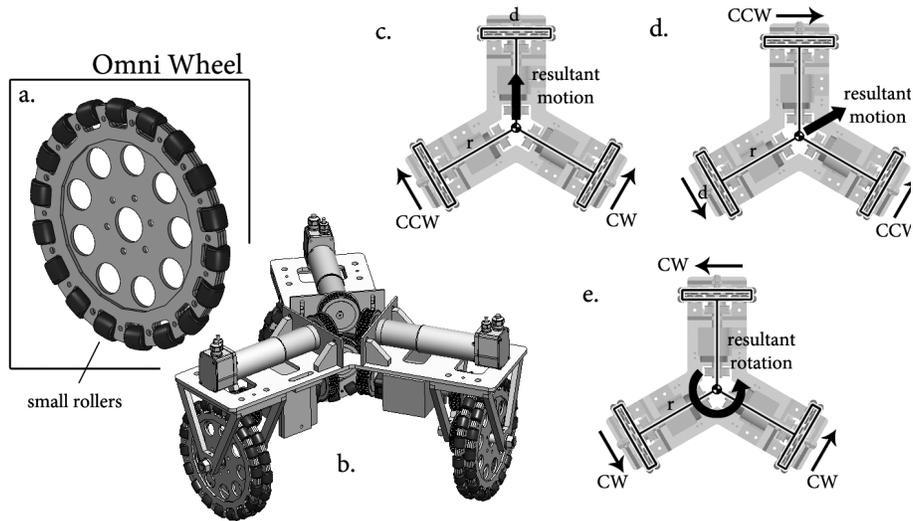
Mode of Transport

While an anthropomorphic design may seem desirable for its appearance alone in HCRs, dynamically stable legged locomotion is still an inefficient, dangerous, and developing area. As each leg requires at least three degrees of freedom (DoF)** to position its end effectors in space, bipedal or quadrupedal robots quickly increase in weight, cost, footprint, and especially control complexity. As an alternative to these complex DoFs, a system with three wheels would provide energy efficiency, great stability, and mechanical simplicity, allowing for more advanced sensing and control. A detailed comparison of various state-of-the-art wheeled platforms can be found in [20]. For example, Rollin' Justin [21] employs four casters for mobility, which are wheels that can swivel on a pivot to change direction of rolling. In contrast, we settled on omni wheels in a triangular configuration to achieve a simpler omni-directional mode of transportation. Our selected omni wheels are 8 inches in diameter, with smaller unrestrained rollers around the circumference (Figure 2). These small $\frac{3}{4}$ inch diameter rollers can spin freely, giving a passive degree of movement perpendicular to the rolling direction. When coupled in a triangular configuration, three wheels create a holonomic driving system, meaning that three actuations match the three free DoFs (in x,y direction and θ rotation). This simplistic design minimizes constructing resources, and allows for more intuitive control algorithms (Figure 2). However, this design also amplifies one simple limitation: conventional wheels cannot roll over a disturbance higher than its radius. Hence, the small $\frac{3}{4}$ inch diameter rollers on omni wheels limit the base to traversing in mild indoor environments. In future upgrade of the systems, existing omni wheels design could be replaced by different configurations or sizes to increase mobility.

** For clarification, DoF is the parameter that defines a subject's configuration and location; for example, the human elbow has one DoF, the bending angle, to define its position.

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Figure 2 a.) isometric view of a single omni wheel, b.) model view of lower base assembly; for more information, please view Figure 3 for component details. c.) & d.) & e.) examples of operation from bottom view. CW represents clockwise wheel rotation, CCW represents counterclockwise wheel rotation.



Compliance and Backlash

As previously mentioned, safety is the most fundamental requirement for designing HCRs; In order for the mobile base to react safely during planned or unplanned collision, we focus on incorporating and improving torque sensing capability in Trikey 2012. With UT's Whole Body Controller (WBC), the control framework would ultimately translate these wheels torque reading to forces in the humanoid's reference frame, giving it the capability to counter disturbance [16]. With this in mind, there are several ways to achieve force and torque sensing. For example, emerging as a new promising research area, series elastic actuators incorporate a spring between the motor and output, hence force is calculated by measuring the spring deflection (Hook's Law: force = spring coefficient \times deflection) [14]. In addition, there are other simpler and more robust alternatives using strain gauges, hydraulic, pneumatic changes. Off-the-shelf sensors usually come as a load cell package with all sensor circuitry included. Hence, we utilized a strain gauge based rotary shaft torque sensor for its precision, accuracy, and ease of implementation.

However, in order to take advantage of the torque sensor and maximize compliant performance, serious consideration had to be given to the drive train to minimize backlash. Backlash is the clearance between mating components, such as teeth in gears or pulleys. It is commonplace in almost all transmission, except in specialized gears like Harmonic Drive [22]. Backlash values in planetary gears usually range below one degree or one millimeter, negligibly small in traditional application. Unfortunately, in the case of torque sensing,

backlash contributes to discrete spikes torque. The rotating load suddenly change as the teeth momentarily engages and disengages, creating undesirable impact forces. Control algorithms would then have difficulty in compensating these sharp changes of value to effectively achieve human-robot interaction. Furthermore, backlash is cumulative in a drive train; when the output is reversed in direction, the system would travel the total backlash distance before re-meshing with the input gear. In Trikey 2012, we reduced backlash by replacing the highly inefficient miter gear from previous design to low backlash timing belt. Even though backlash has been significantly reduced, residual back remains in the system due to planetary gearbox. To remove this backlash, future upgrade could use Harmonic Drive, which is a strain wave gear that utilizes the flexibility and elasticity of metal, deforming to the profile of the teeth mechanism.

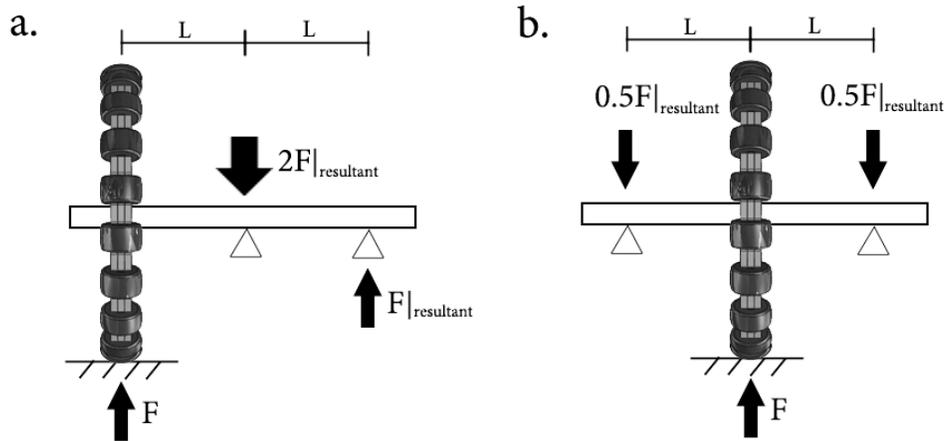
Friction and Load Distribution

Besides backlash, friction also degrades the performance of the mobile base and torque sensing capability. Friction is the force that resists motion between solid or fluid surfaces, transferring part of the kinetic energy into heat, hence creating undesirable outcomes. First, an improperly designed robot with high friction would require more input force to safely steer and react to disturbances. Second, friction is difficult to model precisely. While frictional force is usually described as a linear function of normal forces ($\text{Force} = \text{Coefficient of Friction} \times \text{Normal Force}$), it is merely an approximated empirical formula. The underlying physics are complex and nonlinear. Therefore, a control algorithm that finetunes a friction model would only be partially valid. Third, the static friction between the load and the sensing component dictates, hence limits, the responsiveness of the torque sensing. For example in Figure 2, the force from the environment would apply to the omni wheels, move through the bearings (friction source), transmit through the timing belts (friction sources), before finally deliver to the torque sensor. Therefore, if the bearings and timing belts have one newton-meter of static friction, external forces have to apply an equal amount before the mobile base starts moving or sensing the torque. The static friction model would then morph into a kinetic friction model. Furthermore, the same principle applies between the driving force and sensing component. To remedy this problem, consideration has been taken to decrease internal normal forces, and shorten the drive train path.

Figure 3 showcases the wheel-body configurations that negotiate between convenience and load distribution. On the left, wheel is mounted from the side like car tires, making the assembly more convenient, but it introduces a higher normal load on the support bearings due to moments. Notably, automobiles do not experience this moment imbalance since two wheels are connected to the same axle, a configuration impossible with our triangular wheels placement. Contrastingly in the diagram on the right, the wheel is slid up to the frame like bicycle tires. It requires the system to be lifted higher for assembly,

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Figure 3 a.) wheel is mounted to the side like car tires, b.) wheel is mounted between supports like bike tires, a configuration that creates less internal reaction forces.



but distributes the load more evenly, hence minimizing internal normal forces and friction. We employed the latter approach for Trikey 2012.

Assembly Consideration

Before the complete mechanical redesign of Trikey 2012, the previous versions had a convoluted frame design. Structural elements were locked into each other; individual components were inaccessible without complete robot disassembly. In a research and development environment, it renders important maintenances, troubleshooting, and upgrades nearly impossible. This emphasizes that all good engineering design must keep ease of assembly and adjustability as a high priority. As shown in the Figure 4, each drive train component separately mounts onto the main frame, focusing on modularity. For example, a different motor can be adapted to the base plate by mounting bracket and pulley replacement. Common off-the-shelf parts, such as aluminum extrusions, are used frequently. They allow for versatile configuration of the electronics, computers, and battery systems in the overall mobile base design. In conclusion, it is also important to allowing for adjustments in every mounting element (for example, incorporate slots and bigger through holes versus using countersink hole).

Results

To validate the aforementioned considerations, an experimental comparison was performed after the construction of Trikey 2012 to highlight friction improvements. In the experiment, a step unit torque input of 0.1 N-m was applied to a free-floating wheel for one second on both Trikey 2012 and the previous base. The averaged angular velocity responses from a couple representative trails were recorded and examined in Figure 5.

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Figure 4

a.) maxon motor, b.) planetary gearhead, c.) motor mounting bracket, d.) base plate, e.) pulleys, f.) torque sensor, g.) wheels mounting frame, h.) double-stacked omni wheels

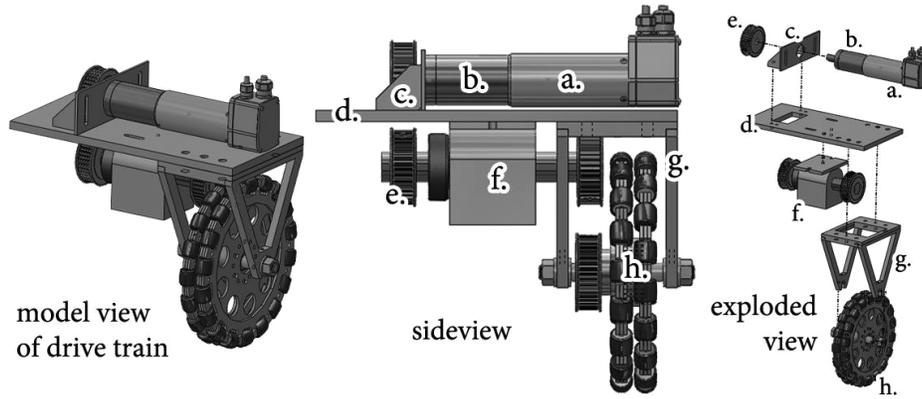
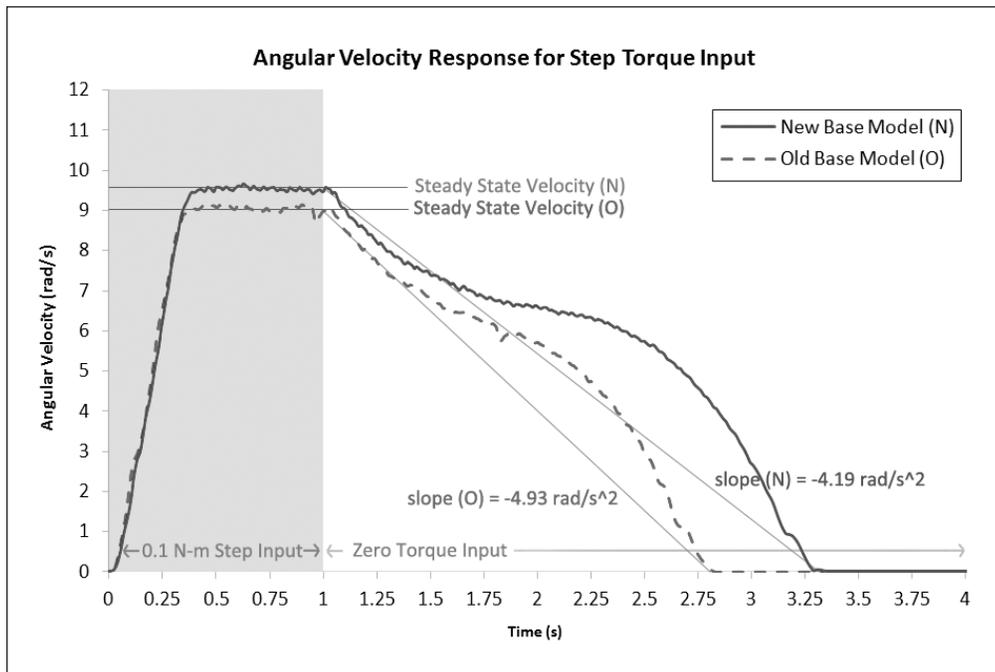


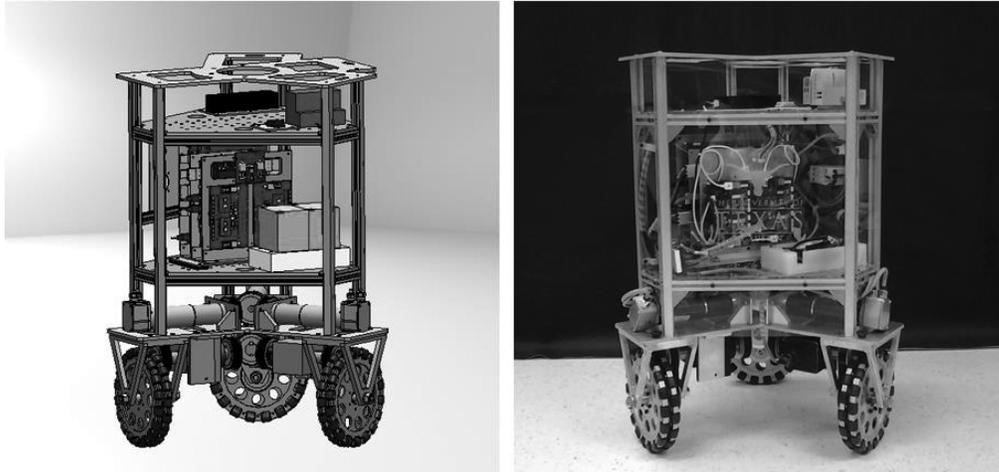
Figure 5

Experimental result of a unit step torque input for Trikey 2012 and previous model. Steady state velocities and deceleration rates are highlighted as criteria to examine friction improvements.



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Figure 6 | Left: Trikey 2012 in CAD software Solidworks, Right: picture of Trikey 2012



Without friction, a rotating system driven by a constant torque input would approach infinite velocity, with the slope dependent on inertia. Therefore, steady state velocity represents an equilibrium where the velocity-dependent frictional force becomes equivalent to the input torque. From Figure 5, the experiment shows that Trikey 2012 (9.6 rad/s) achieves a 6.7% higher steady state velocity than the previous model (9.0 rad/s) for a 0.1 N-m torque input. And after one second of torque input, Trikey 2012 coasted to a stop at a 15% slower rate (-4.19 rad/s^2) than the previous model (-4.93 rad/s^2). While motor's back-EMF contributed to the coasting in both models, friction was the sole influence on the different performance. Therefore, Trikey 2012's drive train exhibited a measurable better performance (with lower friction) than previous model through this experiment.

Conclusion

With the aforementioned considerations, we have designed and built a state-of-the-art mobile base with compliance ability. First, this paper gives a recap of the current state and support for robotics, such as U.S. administration's initiatives and industry's commercial pursuits. Second, we introduce the need for Human-Centered Robots and propose several primary directives such as safety, mobility, and precision. Third, the paper discusses the significant topics we considered when designing Trikey 2012. In order to create safe HCRs, compliant is incorporated into the mechanical capability. Then reducing backlash, friction, and load distribution became design priority to achieve high-performance compliance. However, all these discussions were merely a small summary of the Trikey 2012 project. To limit the scope of the paper, and to cater a general educated audience, details about the electronics and control systems have been omitted. As they deserve discussion in their own light, please refer to [16], [20], [23] for further information.

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Biological and Hyrdological Characteristics of Coastal Cenote Habitats Surrounding Akumal, Quintana Roo, Mexico

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*Undergraduate
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*Volume 12
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Emily Lantz

Abstract

The human population of the Yucatan Peninsula is rising at a rapid rate, bringing vast changes to the landscape of the area. As local populations grow, the amount of nutrient-rich wastewater leaching into the karst-limestone bedrock of the coastal watershed is increasing. Cenotes are considered ideal environments for assessing human impact on coastal habitats due to their proximity to the tropical reefs of the Caribbean Sea. In order to assess the environmental characteristics of the Akumal region of Quintana Roo, Mexico, water quality measurements, including levels of ammonium, an indicator

of nutrient loading in the system, were collected at three cenotes in May and June 2011. Benthic macroalgae, the dominant producers in cenotes, were sampled and identified as an indicator of the biodiversity of each system. Diversity tended to be negatively correlated with ammonium levels, as well as distance to human populations. Yal-Kú Chico, considered accessible only by boat and isolated from urban populations, showed the highest algal diversity. Conversely, Laguna Lagartos, which lies in close proximity to urbanized areas, showed the lowest algal diversity. Nutrient levels in cenotes were highly variable; a drop in ammonium levels from 9.2 μM to 0 μM was measured after a heavy rain. This variation shows that cenote systems are highly responsive to the influx and outflow of available water.

Keywords: Karst system, cenote, nutrient analysis, coastal ecosystems, Mexico, Yucatan

Introduction

Cenotes, often synonymous with the term sinkhole, are geological formations primarily located in the Yucatan Peninsula. Collapsed cave systems form in the porous karst limestone prevalent in the area, which result in pools that form from subterranean water sources. These water sources are essentially underground aqueducts that allow extensive water movement to the Caribbean coast. For most of the year the cenotes and their water sources are the main supply of potable water for the people who inhabit the area (MacSwiney *et al.*, 2007). While the water starts from fresh sources of groundwater, it becomes more brackish as it approaches the coastline.

As the human population grows along the Caribbean coast, human impacts will increasingly threaten coastal ecosystems. Metcalfe *et al.* (2010) found that pharmaceuticals, personal care products, herbicides, and pesticides are present in the karst aquifer systems as a result of domestic sewage and runoff from highways and other impermeable surfaces. Additional anthropogenic effects such as cultural eutrophication also negatively alter coastal ecosystems and pose serious threats to coral reefs, mangrove forests, seagrass meadows, and salt marshes (Hughes *et al.*, 2003; Pandolfi *et al.*, 2003; Duarte *et al.*, 2008). Eutrophication can contribute to declines in seagrass meadows and coral reefs (Short and Wyllie-Echeverria, 1996; Lapointe, 1997). Therefore, the study of cenotes and the underground aquifer systems that feed them is crucial to understanding the coastal ecology of the Caribbean due to their importance to the local inhabitants and biota.

Cenotes are a vital component of the coastal ecology of the Yucatan Peninsula. In 2000, an estimated 99% of the freshwater flux to the Caribbean along the coastline of the Yucatan Peninsula was contributed by submarine groundwater discharge (Worthington *et al.*, 2000). Mutchler *et al.* (2007) concluded that nutrient levels and $\delta^{15}\text{N}$ of NO_3 tended to be higher in systems with greater freshwater influence, and were not different between

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the more developed Akumal Bay and the less developed Xa'ak region. Similar conclusions were made including that systems with carbonate sediments typically had high levels of dissolved inorganic nitrogen (DIN), but little soluble reactive phosphorus, or SRP (D'Elia *et al.*, 1981; Lapointe *et al.*, 1990; Lapointe and Clark, 1992).

Studies have also found that there is an extensive variety of fauna, including both fresh and salt water species, in the cenotes of the Yucatan Peninsula: the cichlid *Cichlasoma urophthalmus* has been identified as one of the most abundant fish species (Poot-Lopez *et al.*, 2009). However, insufficient additional biological data on the flora and fauna inhabiting these karst sinkholes is present in current scientific literature. While the general biological diversity and cenote features have been assessed on Cozumel Island off the coast of Akumal Bay in 2007 (Mejia-Ortiz *et al.*, 2007), general information concerning the biological and hydrological aspects of cenotes on the northeastern coast of the Yucatan Peninsula is still lacking. Therefore, our study attempted to further the known information concerning several cenotes surrounding Akumal, Quintana Roo, Mexico area.

Materials and Methods

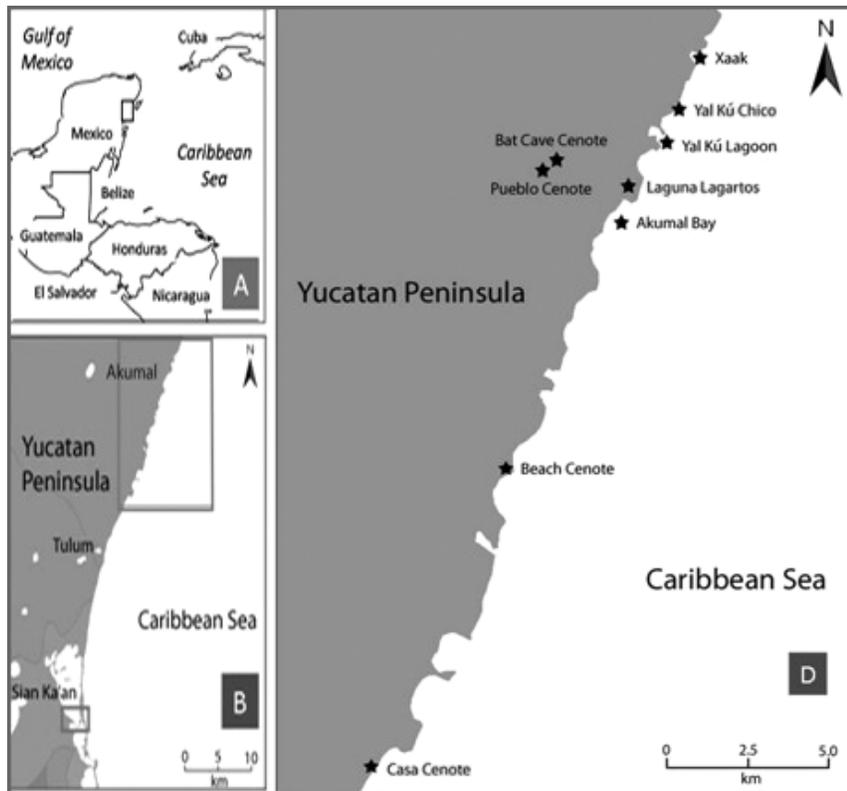
Study Area

This study was conducted in May and early June 2011 along the Caribbean coast of the Yucatan Peninsula in Quintana Roo, Mexico (Fig. 1). Akumal Bay is a small embayment located adjacent to the resort area of Akumal, Mexico. Akumal Bay has no consistent surface water inputs, and the Mesoamerican Barrier Reef protects the bay's outer edge. In addition to the village of Akumal, numerous resorts and vacation homes surround Akumal Bay (Mutchler *et al.*, 2007). Based on groundwater geochemistry, the Yucatan Peninsula can be divided into six hydrogeochemical and physiographic regions: Chicxulub Sedimentary Basin, Cenote Ring, Pockmarked Terrain, Ticul fault zone, Holbox Fracture Zone-Xel-Ha Zone, and the Evaporite Region. Akumal bay is located in the Holbox Fracture Zone of northern Quintana Roo. The Holbox Fracture Zone-Xel-Ha Zone is a regional feature within the karst plain of northeastern Yucatan. This zone consists of greater than 100-kilometer chains of elongated solution depressions where water movement is generally northward (Perry *et al.*, 2007).

Three study sites along the Yucatan coast were chosen for this research; the first was Yal-Ku Chico, a classic salt wedge system located north of Akumal near Xa'ak bay. Yal-Ku Chico represents the outermost location of groundwater, where freshwater flows into the ocean and tidal influence are at its greatest. The second site was Laguna Lagartos, an enclosed and nearly freshwater lagoon system located in the jungle directly outside of Akumal. Thick mats of green algae *Cladophora* sp. and *Ulva* sp. cover a large portion of the lagoon's surface. The final site was Cenote Manati and its ocean outlet Casa Cenote, located south of Akumal near Tulum. Cenote Manati is a sinkhole that formed as the ceiling of an

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Figure 1 | The area of study sites on the Yucatan: Akumal, Quintana Roo, Mexico modified from (Mutchler *et al.*, 2010).



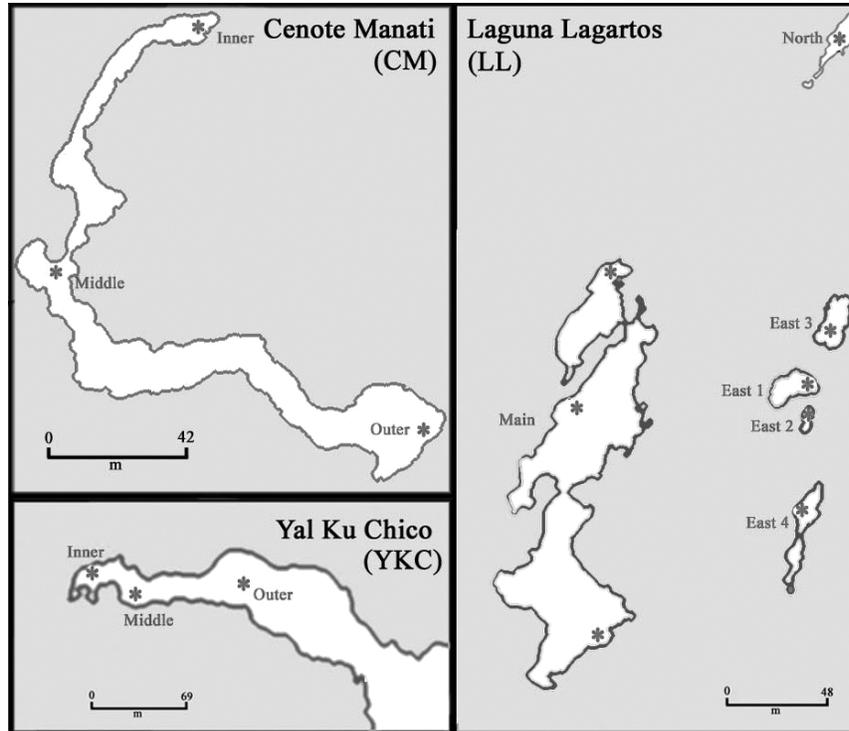
underground cave collapsed and exposed the water under the karst limestone bedrock (Mutchler *et al.* 2010). Water enters Cenote Manati via subsurface flow of groundwater and exits through an underground cave that upwells in the Caribbean a few meters offshore (Mutchler *et al.* 2010). Other sites along the Caribbean coast, such as Yal-Ku Lagoon and Akumal Bay, will be used as a comparison. Yal-Ku Lagoon is similar to Yal-Ku Chico but is larger and connected to Laguna Lagartos through subsurface groundwater flow (Mutchler *et al.* 2010).

Sample Collection and Analysis

General water quality measurements including water column depth, temperature, dissolved oxygen, salinity, and pH were measured *in situ* with a YSI 600XLM data sonde. Measurements were taken from the surface to the substrate at one-meter intervals, and the bottom depth was also recorded. If only shallow depths were present (less than 1 meter), measurements were taken only at the surface. These measurements were collected during varying weather conditions whenever possible to determine how the water quality

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Figure 2 | Location of study sites. The (*) indicates sample stations within a study site.



changed under differing circumstances. Replicate measurements taken on different days were collected at the same locations within each of the sites so data could be compared. Sonde data was collected from three locations within each cenote (Fig. 2): outer (nearest the mouth), middle, and inner (nearest the inflow source). In order to reach the middle and inner locations, the sonde was transported by kayak to the desired location to ensure that the equipment stayed dry and serviceable. Because it is in close proximity to the ocean, the water quality of Cenote Manati was expected to be influenced by the ebb and flood of the tidal regime. For this reason, sonde measurements were taken at multiple times throughout the tidal cycle to verify our expectations of tidal influence. These measurements were taken at both the outer cenote location and the adjacent beach side locations.

Flow meters were placed at the inner and outer locations in both Yal-Ku Chico and Cenote Manati. A Sea-gear Corp. MF315 flow meter was suspended vertically at 0.5 meters of depth in the water column, parallel to the bottom, using a cluster of three air-filled water bottles on the top and a weighted water bottle on the bottom. The starting revolution count and time were noted before deployment, and the ending revolution count and time were recorded after collection. Using the number of revolutions recorded and the amount

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of time the device had been deployed, an accurate assessment of water flow could be determined at each location.

Three water samples were collected in plastic bottles for nutrient analysis at the same locations of the sonde measurements (surface and depth) and were immediately placed on ice in a dark container until analysis could be performed. Analysis of the water samples occurred at the Centro Ecológico Akumal laboratory on the same day as collection. Total ammonium concentration was determined for each sample based on the fluorometry technique described in Holmes *et al.* (1999) and Taylor *et al.* (2007). Background fluorescence was taken from one sample at each location and used in calculating ammonium concentrations for samples of the same location. Matrix effects were calculated from the first sample taken and used in all subsequent calculations regardless of location.

To assess biodiversity of the cenotes, a qualitative rather than quantitative approach was implemented. To assess flora and macroalgae diversity, samples were collected in both the water column and on the bottom substrate at the inner, middle, and outer locations. Diving equipment was used in Cenote Manati to collect algae at depths not easily accessible by free diving. Free-diving in Yal-Ku Chico, Yal-Ku Lagoon and Akumal Bay was sufficient to obtain algal samples, but samples were not collected in this manner in Laguna Lagartos. Because of known high nutrient levels in Laguna Lagartos (Mutchler *et al.*, 2007), swimming to collect algae was not conducted to prevent extensive contact with any contaminants or high bacterial levels in the water. Instead, samples were collected by hand from the algal mats floating at the surface.

Location of algae (inner, middle, outer) and depth (above or below one meter) were also noted in order to determine the abundance and diversity of species in each algal family due to the changes in salinity with depth and distance from freshwater sources. All specimens were collected in plastic bags and stored on ice for further analysis and identification in a temporary laboratory at the Club Akumal Caribe. Specimens were studied under dissecting and compound microscopes and then identified to the genus or species level using appropriate keys (Littler & Littler, 2000; Littler *et al.*, 1989). The scientific name of each alga was recorded if it had not been previously identified at the corresponding location and was tallied and grouped by division (Rhodophyta, Phaeophyta or Chlorophyta). The total biomass of each species was not recorded. A Shannon-Weiner Diversity Index, including both H' (species diversity) and E (evenness) were calculated for each of the samples at a given site using:

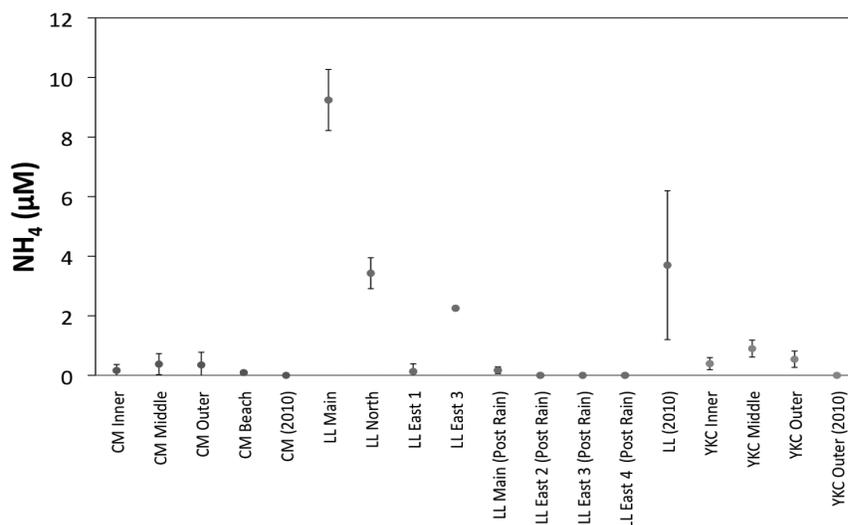
$$H' = - \sum_{i=1}^s p_i \ln p_i$$

where p_i is the relative abundance of a species within a zone, divided by the total number of species observed in that zone.

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Figure 3

Water column concentration of ammonium at various sampling site (means \pm standard deviation). CM = Cenote Manati, LL =Laguna Lagartos, YKC = Yal-Kú Chico. Each of these sites is divided into multiple stations. Note the difference between pre-rain ammonium levels (LL main) and post-precipitation levels at the same site.



Pelagic algae such as *Sargassum* spp. were not recorded because they are not an indicator of the system, but rather a byproduct of offshore activity (Biber 2007). All other biota including, but not limited to, microalgae, seagrasses, terrestrial vegetation, and fish were also noted.

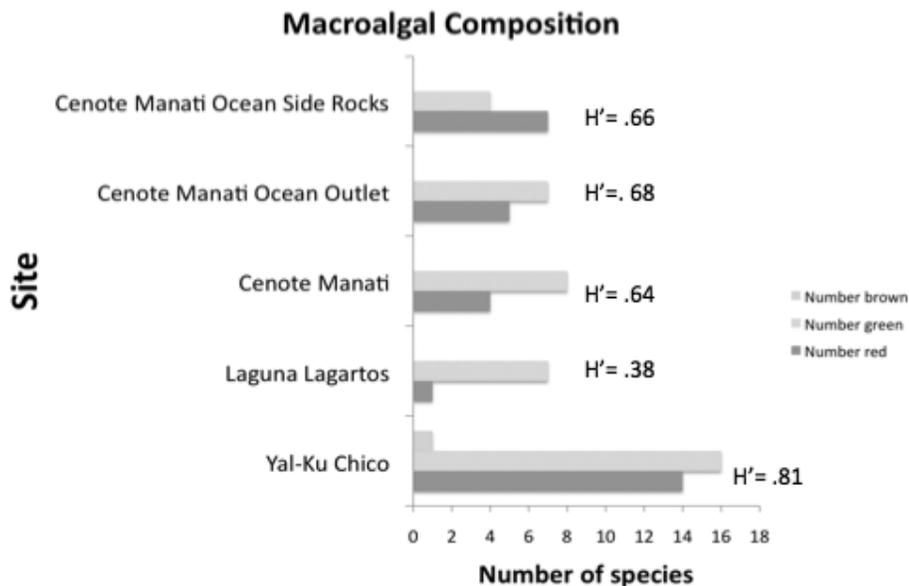
Percent coverage of algae was recorded at Yal-Ku Chico and Cenote Manati. At each of the locations within the cenote (outer, middle, inner), a transect line was laid down parallel to the mouth and across the width of the cenote; this transect was used to take total percent coverage of algae on the bottom at five meter intervals and width of two meters using a quadrat. The substrate at each interval was also recorded. Because of known high nutrient levels in Laguna Lagartos (Mutchler et al., 2007), transects were not performed to prevent extensive contact with any contaminants or high bacterial levels in the water.

Results

All sonde measurements can be found in Appendix A. Water column characteristics of Yal-Ku Chico showed typical salt wedge characteristics in all parts of the inlet at the time of sampling. Warmer seawater formed a distinct bottom layer approximately one meter below the surface, with colder freshwater forming an overriding surface layer. Salinity was at its greatest (34.9) at the outer bottom region of the inlet and lowest (10.53) at the inner upper region. Temperature and dissolved oxygen (DO) showed similar patterns with highest levels in the outer bottom region (28.8 C°, 5.59 mg L⁻¹) and lowest levels in the

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Figure 4 | Composition of algal divisions at different sites surveyed from 20 May to 3 June 2011. H' indicates the Shannon-Weiner index of each site in relation to algal composition.



inner upper region ($26.48\text{ }^{\circ}\text{C}$, 2.5 mg L^{-1}). Laguna Lagartos water column characteristics were quite uniform in depth as well as between locations throughout the lagoon system. Salinity, temperature, and DO ranged from about 8-9, $26\text{-}28\text{ }^{\circ}\text{C}$, and $1\text{-}5\text{ mg L}^{-1}$. Cenote Manati showed stratification in the water column, and because Cenote Manati was tidally influenced, water column characteristics varied slightly over time with tidal cycle.

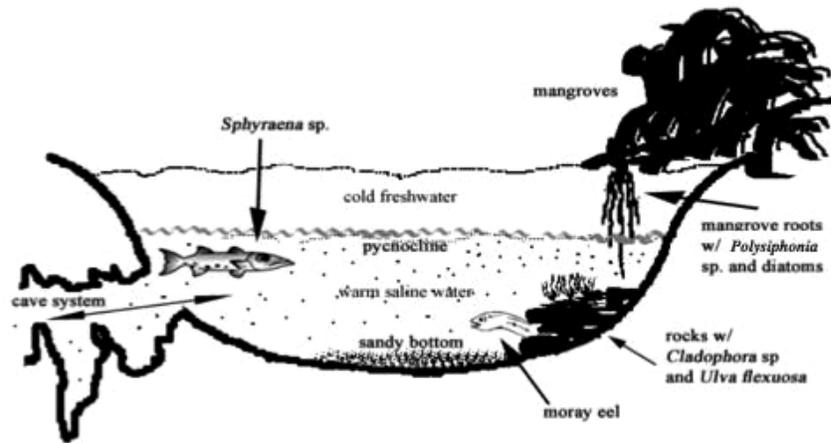
Flow meters were used in Yal-Ku Chico and Cenote Manati but proved to be ineffective at measuring flow in these study sites. The number of revolutions (if any) highly varied between inner and outer regions of each study site and flow was suspected to be too weak to be accurately and precisely measured by the Sea Gear Corp. MF315 flow meter.

Water column NH_4^+ was most concentrated in the Laguna Lagartos system (Fig. 3), with NH_4^+ highly variable within the system. The Main lagoon (Fig. 2) had the highest NH_4^+ concentration ($9.2 \pm 1.0\text{ }\mu\text{M}$; $n=4$) followed by North ($3.4 \pm 0.5\text{ }\mu\text{M}$; $n=5$). However, the Laguna Lagartos Main ammonium values changed significantly with weather conditions, with a pre-rain value of $9.2 \pm 1.0\text{ }\mu\text{M}$ and a post-rain value of $0.17 \pm 12\text{ }\mu\text{M}$. Despite their close proximity to each other, the eastern lagoons (East 1, 2, 3, and 4) showed variation in their nutrient levels. East 3 had the highest NH_4^+ concentration ($1.1 \pm 1.6\text{ }\mu\text{M}$; $n=2$) followed by East 1 ($0.1 \pm 3\text{ }\mu\text{M}$; $n=4$). East 2 and East 4 had no measurable NH_4^+ . Yal-Ku Chico had varying NH_4^+ concentrations in the inner ($0.4 \pm 0.2\text{ }\mu\text{M}$; $n=2$), middle ($0.9 \pm 3\text{ }\mu\text{M}$; $n=2$), and outer ($0.5 \pm 3\text{ }\mu\text{M}$; $n=6$) regions. Cenote Manati also showed variability among inner ($0.2 \pm 0.2\text{ }\mu\text{M}$; $n=3$), middle ($0.4 \pm 4\text{ }\mu\text{M}$; $n=3$), and outer ($0.3 \pm 4\text{ }\mu\text{M}$; $n=7$) regions. Because averages

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Figure 5a

A depiction of the vertical profile of Cenote Manati's outermost location, including the predominating flora and fauna as observed in situ. The arrow depicts the continuation of the aquifer underground to the ocean, and the influx of saline water. The depth of the pycnocline varied throughout sampling as tidal regime varied.



were taken across multiple depths and dates, stratification and weather conditions played a major role in the variability of the ammonium concentrations within study sites.

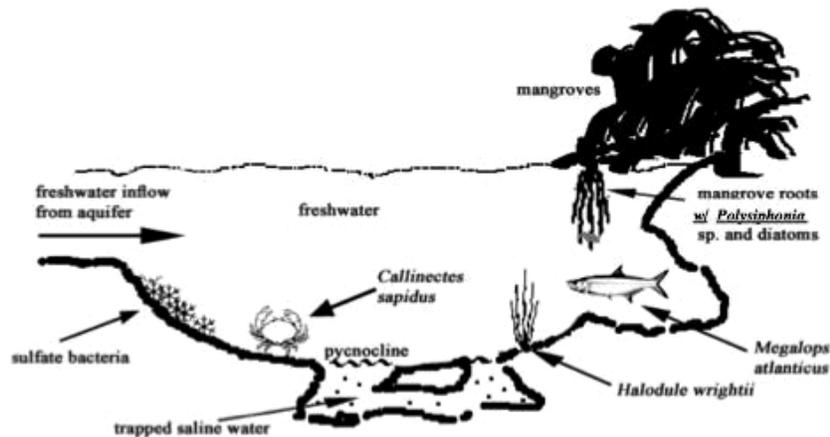
A complete algal species list for each site can be found in Appendix B. In all cenotes, green algal dominance was evident (Fig. 4). Cenote Manati (green $n=8$, red $n=4$, brown $n=0$) and Laguna Lagartos (green $n=7$, red $n=1$, brown $n=0$) tended to be dominated by green algae. Laguna Lagartos showed a low H' value of .38, where as Cenote Manati showed an intermediate H' value of .64. The Cenote Manati ocean outlet also showed this dominance (green $n=7$, red $n=5$, brown $n=0$) and an H' value of 0.68. Environments directly linked to the ocean had a fairly balanced composition of red and green algae. Yal-Ku Lagoon (green $n=13$, red $n=14$, brown $n=3$) and Yal-Ku Chico (green $n=16$, red $n=14$, brown $n=1$) showed a mixed composition of algae. Akumal Bay (green $n=8$, red $n=16$, brown $n=5$) and Cenote Manati ocean side rocks (green $n=4$, red $n=7$, brown $n=0$) had a similar mixed composition. Yal-Ku Chico showed a high H' value of 0.81.

Cenote Manati (Fig. 5) was also home to many other forms of biota including barracuda (*Sphyaena sp.*), tarpon (*Megalops atlanticus*), Mayan cichlids (*Cichlasoma urophthalmus*), blue crab (*Callinectes sapidus*), shoal grass (*Halodule wrightii*), and sulfate bacteria. Diatoms and cyanobacteria were present in all sites.

Percent algal coverage (as found in Appendix C) was variable among Cenote Manati and Yal-Ku Chico, but showed strong association with substrate type. Percent coverage on rocky substrate was very high (80-100%), sandy substrate had little to no coverage (0-5%) and mixed substrate had intermediate coverage (55-95%). Mangrove roots also showed high algal coverage (95%) similar to rocky substrates.

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Figure 5b A depiction of the vertical profile of Cenote Manati's innermost location, including the predominating flora and fauna as observed in situ. Trapped saline water originates from the influx of tidal ocean water, which sinks to the bottom.



Discussion

Water Quality and Nutrients

At Cenote Manati, sonde measurements were taken at the ebb and flood of the tides in order to determine the changes in water chemistry as the saline ocean water flows in and out of the cenote through underground tunnels that connect the cenote to the ocean. Of the parameters tested, only two showed distinct change, the salinity and temperature, with depth and type of tide. During the flood tide, salinity ranged from approximately 9-10 at the surface of the cenote to a max of around 13 at depth at 0800 hours. A steady decrease occurred in the salinity at depth until 1600 hours when there was a significant increase to approximately 30. Concurrently, the salinity at the surface stayed fairly consistent in the 9-10 range throughout the cycle of the tides. This consistent surface salinity is likely due to a constant source of freshwater into the cenote from the karst aquifer system.

The temperature in Cenote Manati stayed fairly stable throughout the majority of the measurements in the 25-26 degrees Celsius range, showing only a slight increase in temperature with depth in the morning measurements. Higher temperatures at the surface of the water followed by a slight drop in temperature at one meter can be explained by the heating of the surface waters during the day. All measurements taken throughout the day showed an increase in temperature as the sonde approached the bottom of the site except for at 1250 hours. At 1250 hours there was no tidal pressure on the salt water to move inward or on the cenote water to move outward toward the ocean. When the water is in slack tide, the surface waters begin to heat. However, the warmer surface waters do not

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cause an overturn in the water column; the more saline waters stay trapped on the bottom as salinity exerts more of a force on the pycnocline than does temperature. At 1600 hours, the temperature was lower at the surface than at depth, which could be due to a surge of cold fresh water being input into the system coupled with greater amounts of warm saline water entering the cenote with the flood of the tide.

Due to time constraints, continual 12 hour monitoring of Cenote Manati did not take place on 3 June 2011. Had continual monitoring taken place, we would have hoped to see halocline pattern similar to the vertical depth profile taken on 20 May 2011 at 1600 hours, which was consistent with previous profiles done on the cenote (Beddows 2003). The data presented from 20 May 2011 is an extrapolation of previous monitoring data and can be used as a reference for when conditions are similar since the tides across this time span were consistent with only a 2 cm high tide difference. However, the differences in the readings could also possibly be due to inherent changes in weather, people utilizing the cenote differently on each day, or any small tidal differences.

Ammonium as an Indicator of Eutrophic Conditions

The high concentrations of NH_4^+ in Laguna Lagartos Main were markedly higher than previously reported values (Mutchler *et al.* 2007, 2010). High NH_4^+ levels can possibly be attributed to increased wastewater inputs and subsequent nutrient loading due to a corresponding increase in urbanization of the area since the previous study. However, we also noticed a subsequent shift in the NH_4^+ levels after a rain event; the levels dropped from $9.2 \pm 1.0 \mu\text{M}$ to $0.17 \pm 0.12 \mu\text{M}$. This influx of rainwater appeared to flush the cenote of most of its ammonium, leaving fresher water. However, because the karst system has little time to filter the rainwater, future ammonium analyses in the days following a rain event (based on flow rate through the cenote system) could depict unnaturally high values resulting from polluted runoff entering the system. The Laguna Lagartos North site showed NH_4^+ values consistent with previous studies (Mutchler *et al.* 2007, 2010). $\delta^{15}\text{N}$ analyses have been used to ascertain that the nitrogen present in the karst aquifers and cenotes is most likely anthropogenic in origin (Mutchler *et al.* 2010). Conversely, Cenote Manati and Yal-Ku Chico showed relatively low NH_4^+ concentrations (Fig. 3) possibly due to high levels of denitrification by anaerobic bacteria occurring in the karst underground aquifer system and primary productivity *in situ* by the large numbers of algae present in each system. Low levels of dissolved oxygen (Appendix A) present in Cenote Manati and Yal-Ku Chico may enhance use of available nitrogen by anaerobic bacteria as an electron acceptor in place of oxygen. The high variability of nutrients in each system may be attributed to variable weather conditions and irregular wastewater inputs.

Eutrophication, caused by the addition of large amounts of nutrients to a system, can be destructive to ecosystems and may result in a decrease in biodiversity as the hypoxic environment discourages the presence of aerobic fauna. Based on our site map (Fig. 1), we

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could infer that the areas that are the most vulnerable to eutrophication are the ones that are in closest proximity to highly urbanized areas, or urbanization over the recharge zone for each aquifer. The Akumal area contains a topsoil profile of only 3 centimeters above karst fractures and the water table, resulting in little time for the aquifer system to filter the water before it enters the system (Boyer 2008). In addition, due to poor wastewater treatment, water may be returned to the ground before all of the contaminants are fully removed. Laguna Lagartos is less than five kilometers from the Akumal pueblo and is subsequently greatly affected by the human population. Therefore, Laguna Lagartos receives large amounts of organic nutrient inputs from runoff and aquifer intake. Conversely, Yal-Ku Chico and Cenote Manati are relatively far from major centers of human population, and have lower nutrient levels.

The Algae Flora of the Cenotes

At each of the locations, there was a different community composition of macroalgae. For instance, Yal-Ku Chico showed a variety of algae, representative of each of the Rhodophyta, Phaeophyta, and Chlorophyta divisions of algae (Fig. 4). The innermost location, closest to the freshwater inputs contained largely Chlorophyta species (green algae), while the middle and outer areas displayed more Rhodophyta, (red algae), and Phaeophyta (brown algae) species. A similar pattern is seen in Cenote Manati, which consisted of primarily greens near the inflow source and reds near the mouth. Laguna Lagartos was composed primarily of green algae, most likely due to its distance from the ocean, resulting in a relatively stable freshwater environment.

This data reflects the fact that the green algae are the most opportunistic, best competitors, and present in largely nutrient rich areas (Lapointe *et al.*, 1993). The green algae are most characteristic of freshwater systems; therefore, they are more likely to be located nearest the freshwater inflow source or in an area not governed by oceanic influence, such as Laguna Lagartos. The red algae is an indicator of a mixed system, which we see in Yal-Ku Chico as it is a salt wedge system and is constantly subject to the mixing of salt and freshwater. Brown algae are generally pelagic and indicative of nutrient-rich cold water systems and are subsequently likely to only be found in the outermost areas where salt water enters the system.

In nutrient rich areas such as Laguna Lagartos, we would expect the best competitor to exploit the area, resulting in low diversity. This was reflected in the low H' value of 0.34, indicating a system that heavily favors one type of algae: Chlorophyta. However, in an area with limited nutrients, we observe more species in competition with one another, thus creating an environment balanced between good competitors such as green algae, and good colonizers such as the red algae. The brackish, nutrient-limited systems have a higher diversity. For example, Yal-Ku Chico which communicates directly with the Caribbean has an H' value of 0.81, which indicates a habitat that has a more diverse algal community.

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In accordance with the Littler relative dominance paradigm (Littler *et al.*, 1993), the higher diversity may also be related to the relative proximity of the sites to urbanized areas; the more removed a system is, or more pristine it is considered, the higher the community diversity based on macroalgae coverage. Only one algal species was found in all sites that we sampled: *Cladophora* sp. This particular genus can be found in both fresh and saline water (Littler and Littler 2000, Mutchler *et al.* 2010). In our study, macroalgae was used as an indirect marker of biodiversity because the macroalgae act as primary producers, which support the rest of the ecosystem. Thus, the more diversified the algae was in an ecosystem, the more productive the ecosystem, which results in a larger biodiversity of fauna supported.

Based on the algae species and relative abundance present in each of the sites, Yal-Ku Chico is considered the most productive and biodiverse site, with a variety of reds, greens and browns, which indicates that the area can support a large amount of fauna as well. In addition, a site with a variety of algae seemed to be able to support sensitive fauna: Dr. Luis Rocha, a tropical reef fish specialist, identified Rainbow Parrotfish, which is classified as critically endangered, inhabiting the bay. Cenote Manati has a moderate number of algal species, representative of both red and green species, which support a variety of fresh water and marine species in relatively low abundances, as well as a large abundance and diversity of diatoms. However, Laguna Lagartos, which is dominated by green algal species, has a very limited biodiversity consisting of scarce groupings of small fresh water fishes.

The outer transects of both Yal-Ku Chico and Cenote Manati experience almost the same bathymetry: elevated sides with rocky substrate, and a sandy middle, low center. The sandy middle of these locations contains few, if any, algae species. This U-shaped trend is due to the lack of a complex root system that would otherwise allow more algae to take root in the loose sand. In the middle of both of the outermost transects, sand is the most abundant substrate because of the high flow due to water entering and leaving the system continually. However, the rocky substrate of the sides has very high algal percent coverage ranging from 65-100%. An exception to the high algal coverage was the end-point of the outermost Yal-Ku Chico transect, which was coral rubble from the ocean outlet feeding the system. We observed that algae did not appear to grow on the rubble, because the rubble tended to move with the wave action.

Associated Fauna

In Cenote Manati, which is subject to tidal influence, a variety of marine life was observed. In the middle transect, *Halodule wrightii* was growing; this is highly irregular because Cenote Manati tends to have largely limestone substrate which would not be conducive to the root systems of the shoal grass. The inner section was home to a large school of juvenile tarpon, and small barracuda, a primarily saltwater teleost, were seen throughout the cenote. In the crevices deep between the rocks, there were pockets of

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warm salt water that mixed with the freshwater; this stratification is not evident in our sonde measurements because of inaccessibility to these crevices by the sonde. As noted by Poot-Lopez *et al.* (2009) in their survey of cenotes in Quintana Roo, a thriving population of the freshwater cichlid *Cichlasoma urophthalmus*, commonly known as the Mayan cichlid, is present in Cenote Manati (Fig. 5). This mix of primarily salt water and fresh water species indicates a large amount of fluctuation in the salinity levels of Cenote Manati, likely occurring due to regular storms, hurricanes, and tidal influences which may push high salinity water as far as 1 kilometer into the back-reaches of the cenote. Also in this system, large colonies of white anaerobic sulfate bacteria proliferate on rock faces beneath the mangrove roots, indicating that there are large amounts of sulfur present in the cenote, possibly as a result of seawater influx. Sulfur is a common trace element in seawater, through organic inputs, sulfate assimilation reduction as well as sulfide oxidation (Bates *et al.* 1994). However, sulfur is less common in fresh water, indicating that a tidal event must have pushed saline water up into the furthest reaches of the cenote.

In the Laguna Lagartos system, which was largely hypoxic due to high rates of bacterial respiration related to nutrient content (Mutchler *et al.*, 2010), populations of small fish are able to thrive in the top layer of water where large algal mats of *Cladophora* sp. can provide some oxygen via photosynthesis. Larger fish species were also seen deeper in the water column but were unable to be identified.

Yal-Ku Chico, a small cenote that is fed by the Grande Sirena cenote, experiences direct mixing of the warmer, denser salt water from the ocean and the colder fresh water deposited into it. This forms a distinct halocline, visible even without special equipment, due to the differences in salinity and temperature between the two types of water. The halocline probably keeps the teleostean fishes largely confined to the warmer bottom saline layer of the salt wedge due to the extreme changes in water types. The low amount of dissolved oxygen may also dissuade organisms from inhabiting the colder fresh water surface layer. There was also a plethora of gastropods inhabiting Yal-Ku Chico, primarily around the head of the bay. These snails were observed only in the fresh top layer of the water on the rocky shelf, and none were found on the rocky bottom in the lower salt-water layer of the water column.

Conclusion

Cenotes are a dynamic and extremely indicative part of the karst limestone aquifer system in the Yucatan Peninsula. They are invaluable not only to the human population as a vital source of drinking water, but are also critical to the diverse flora and fauna that inhabit them. Multitudes of micro and macro algae constitute the main primary production in these sinkholes. Many invertebrates and fish species rely on this primary production as a food source to support thriving populations. Our study helped to further the knowledge baseline of the water quality and flora and fauna present in the cenotes in the Akumal

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region of Quintana Roo, Mexico. This research has synthesized previous data from both hydrological and biological backgrounds, as well as performing independent surveys on the water chemistry, water quality (as measured by nutrient levels), and biodiversity in order to provide a descriptive study of the dynamic aspects of the karst cenote system.

This study represents the first comprehensive survey (that I am aware) of the algal flora of cenotes on the Yucatan Peninsula. Further studies should focus on both short- and long-term variations in the algal flora in response to changes in the water chemistry and quality. These changes likely affect the inhabitants of the cenotes by rapidly changing what sections of the water column are inhabitable for each particular species. In addition, ammonium or nitrogen analyses of both sediment and water column nutrients should employ spectrophotometric methods to improve accuracy.

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Characterization of nuclear morphology and hypocotyl cell length in *sar1*, *nup98*, and *sar1/nup98* mutants of *Arabidopsis thaliana*

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Abstract

Although the Nuclear Pore Complex (NPC) is important for trafficking macromolecules across the nuclear envelope, proteins of the NPC are also involved in maintaining and regulating nuclear morphology. The NPC of plants has not been fully characterized, and the relationship between nuclear morphology and gross physiology needs to be determined. A major structural component of the NPC, the Nup107-160 subcomplex, contains the nucleoporins *sar1* and Nup98. To determine whether *sar1* and *nup98* affect nuclear morphology, major axis lengths and circularity indices of *sar1*, *nup98*, and

sar1/nup98 knockout nuclei were compared against those of wild type nuclei. Since *sar1* is also involved in auxin signaling and auxin promotes cell elongation and cell division, *sar1* may contribute to hypocotyl cell elongation. Major axes of dark-grown hypocotyl cells were compared against light-grown hypocotyl cells to determine if nucleoporin mutations affect etiolated hypocotyl cell lengths. We found that wild type and *sar1/nup98* had the smallest nuclei while mutant nuclei were more circular. *sar1*, *nup98*, and *sar1/nup98* hypocotyl cells exhibit the same capacity to elongate as wild type hypocotyl cells. However, *nup98* hypocotyl cells may have less capacity to elongate than those of other mutants. Therefore, *sar1* and *nup98* may play roles in maintaining the structure of the nuclear pore complex but do not contribute to hypocotyl cell length growth in the dark. Examining the roles of *sar1* and *nup98* in hypocotyl elongation, especially in regards to auxin signaling, will further our understanding of how nucleoporins regulate plant growth and development.

Introduction

The Nuclear Pore Complex (NPC) is important for trafficking macromolecules across the nuclear envelope. Recent evidence indicates that proteins of the NPC are also involved in maintaining and regulating nuclear morphology (Xu *et al.*, 2007). Though much is known about vertebrate and yeast NPCs, plant NPCs have yet to be fully characterized. It is composed of three subcomplexes: the Nup62 subcomplex (Nup62, Nup58, Nup54, and Nup45), the Nup107-160 subcomplex (Nup160, Nup133, Nup107, Nup96, Nup75, Nup43, Nup37, Seh1, Sec13, and ALADIN) and the Nup93 subcomplex (Nup205, Nup188, Nup155, Nup93, and Nup35). The Nup107-160 subcomplex serves as a structural scaffold in vertebrate NPCs (Xu *et al.*, 2007). It is also responsible for spindle assembly through kinetochores as well as immunity-related mRNA export (Loiodice *et al.*, 2004, Wiermer *et al.*, 2012). We focused on *sar1* and *nup98*, nucleoporins involved in the Nup107-160 subcomplex.

sar1 was initially discovered to be a suppressor of auxin resistance (Xu *et al.* 2007). Auxin is a growth hormone that regulates plant growth and development through cell division, cell elongation, and cell differentiation. Five auxin response loci have been identified: *AXR1*, *AXR2*, *AXR3*, *AXR4*, and *AUX1*. *Axr1* mutants demonstrate a lack of response to auxin, and so, they are auxin-resistant. *IAA17* is a repressor that binds to the promoter of these auxin response genes and inhibits their expression. Therefore, cell division and cell elongation does not occur when *IAA17* is bound. Auxin normally generates ubiquitination of the *IAA17* repressor. This ubiquitination serves as a signal that sends *IAA17* to the 26S proteasome, and *IAA17* is degraded within the proteasome. Transcription of auxin response genes is then able to proceed because the repressor is absent, and the plant can respond to auxin. In the *axr1* mutant, *IAA17* cannot be degraded, so the mutant will not respond to auxin. Therefore, *axr1* is most likely involved in degradation of the repressor. The auxin response was restored in *sar1* and *sar1/axr1* mutants. *sar1* is most likely

involved in transport of mRNA out of the nucleus or transport of protein into the nucleus. Thus, in *sar1* mutants, the mRNA for *IAA17* cannot be exported out of the nucleus to undergo transcription in the cytoplasm or the *IAA17* protein cannot be imported into the nucleus to bind to the promoter of the auxin response genes. *IAA17* is never produced and so, the plant will respond to auxin. In *sar1/axr1* mutants, *IAA17* is never produced, so it can never be degraded and thus, the plants will respond to auxin as well. From these results, *sar1* is epistatic to *axr1* (Cernac *et al.*, 1997).

sar1/sar3 double mutants have an accumulation of poly(A)⁺ RNA in the nucleus; therefore, *sar1* and *sar3* are likely involved in RNA export (Xu *et al.*, 2007). Molecular characterization reveals that *sar1* encodes a protein like the vertebrate nucleoporin Nup160 (Parry *et al.*, 2006). *sar1* plants are also shorter than wild type and have abnormal leaves, earlier flower development, and less cell division in the roots.

Nup98 is a nucleoporin in the Nup107-160 subcomplex that moves dynamically on and off the nuclear pore. Blocking transcription of RNA polymerase I and II prevents the mobility of *nup98* on the nuclear pore. Thus, *nup98* most likely interacts with RNA polymerase I and II to promote transcription (Griffis *et al.* 2004). One domain is important for NPC localization on the nuclear membrane, and other regions of the protein affect the stability of the association with the pore. *Nup98* plants exhibit no physiological mutant phenotype.

However, the role of *sar1* and *nup98* in nuclear morphology is not clear. Nuclei of mutants such as *nup136/nup1* have shorter major axes and are more circular than wild type nuclei (Tamura *et al.*, 2010). Nup136/Nup1 may interact with the nuclear skeleton, nuclear lamina, and the cytoskeleton, as these help maintain and regulate nuclear morphology.

The relationship between hypocotyl length and nuclei size also has yet to be established. It is known that *Arabidopsis* hypocotyl cells elongate under dark conditions (Gendreau *et al.*, 1997). *sar1* and *nup98* nucleoporins may contribute to hypocotyl cell elongation.

In this study, we were interested in the effect of *sar1* and *nup98* on nuclear morphology. We also asked how *sar1* and *nup98* would affect hypocotyl length in the light and the dark. *sar1* is involved in the auxin pathway, and auxin is responsible for cell division and cell elongation. The hypocotyl is an ideal area for studying these effects, as *sar1/nup98* mutants may have defects in hypocotyl cell elongation.

Major axis lengths and circularity indices were determined for wild type, *sar1*, *nup98*, and *sar1/nup98* nuclei. We found that wild type and *sar1/nup98* nuclei were smaller than *sar1* and *nup98* mutants. *sar1* and *nup98* mutants exhibited more circular nuclei than wild type, while *sar1/nup98* exhibited the most circular nuclei. Major axes of hypocotyl cell lengths in light and dark conditions were also measured for all lineages. *sar1*, *nup98*, and *sar1/nup98* hypocotyl cells elongate in the dark similarly to wild type hypocotyl cells. Therefore, *sar1* and *nup98* may interact with the nuclear skeleton, nuclear lamina, and the cytoskeleton, but do not contribute to hypocotyl cell length in the dark.

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Determining the effect of *sar1* and *nup98* knockouts on nuclear morphology and hypocotyl cell length may contribute to future investigation of the role of the *sehl* and *nup98* nucleoporins in *Arabidopsis thaliana*. Examining the roles of *sar1* and *nup98* in hypocotyl elongation, especially in regards to auxin signaling, will further our understanding of nucleoporins in plant growth and development.

Methods

Plant Materials and Growth Conditions

Wild type, *sar1*, *nup98*, and *sar1/nup98* mutant *Arabidopsis thaliana* lines were used. The 4 genotypes were sterilized in 50% bleach and 0.1% Triton X. They were stratified at 4°C for 4 days. Plants were then placed in light and dark conditions. In dark conditions, plants were wrapped in foil for 1 week. In light conditions, plants were exposed to light for 1 week at 22°C.

Nuclei extraction

Leaves were fixed in 4% formaldehyde in Tris buffer (4% formaldehyde, 10 mM Tris-HCl pH 7.5, 10 mM NaEDTA, 100 mM NaCl) and rotated at 4°C for 20 minutes. Formaldehyde was removed and the mixture was washed 2x10 minutes with Tris buffer at 4°C. For nuclei extraction, leaves were ground in LB01 buffer (15 mM Tris-HCl pH 7.5, 2 mM NaEDTA, 0.5 mM spermine-4HCl, 80 mM KCl, 20 mM NaCl, 0.1% Triton X-100). Lysate was passed through a cell filter.

Sorting buffer (100 mM Tris-HCl pH 7.5, 50 mM KCl, 2 mM MgCl₂, 0.05% Tween-20, 5% sucrose) was added to the nuclei suspensions. Dry nuclei suspensions were fixed to coverslips with cold methanol and incubated for 5 minutes. The methanol was aspirated with two pipettes and washed 10 times. TBST was added immediately after aspirating each wash in order to rehydrate the sample. After washing, TBST was added to the coverslip.

TBST was removed and Vectashield+DAPI was added in order to visualize the nuclei. Nail polish was used to seal the coverslip to the slide.

Imaging Nuclei and Hypocotyl Cells

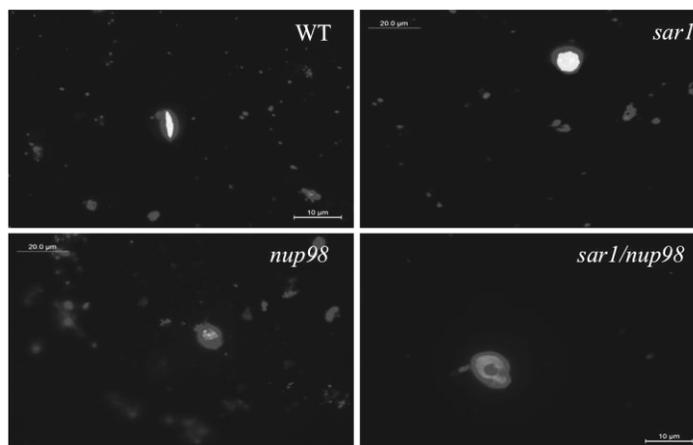
Nuclei from plants were imaged using a Leica DMI4000B inverted microscope with a DAPI filter at 100X. Hypocotyl cells were imaged using a Leica DMI4000B inverted microscope with BF at 20X.

Figure 1

sar1, *nup98*, and *sar1/nup98* nuclei are more circular than wild type.

Images taken using DAPI filter of representative nuclei from: (A) wild type; (B) *sar1*; (C) *nup98* and (D) *sar1/nup98*.

Scale for A and D = 10 μm , B and C = 20 μm .

**Data Collection using Image J**

Major axis length and circularity parameters for all the nuclei were measured using Image J.

Data Analysis with Excel

Averages and standard errors for major axis lengths and circularity indices were calculated using Excel. A student's t-test was also performed to determine significance.

Results

Previous nucleoporin mutants have had altered nuclear morphology, indicating that they may have a role in maintaining nuclear morphology. We were interested in determining whether *sar1* and *nup98* would affect wild type nuclear morphology. Also, since *sar1* plays a role in the auxin pathway, and auxin regulates cell elongation and cell division, we asked if *sar1*, *nup98*, and *sar1/nup98* mutants would have defects in hypocotyl cell elongation.

Changes in *sar1* and *nup98* nuclear morphology would supply information about the roles of *sar1* and *nup98* in regulating and maintaining nuclear morphology. Images of nuclei were taken on a Leica DMI4000B inverted microscope with a DAPI filter to detect differences in nuclear morphology between wild type, *sar1*, *nup98*, and *sar1/nup98* lines. Visually, *sar1*, *nup98*, and *sar1/nup98* mutant nuclei appeared more circular than those of the wild type nuclei (Fig. 1).

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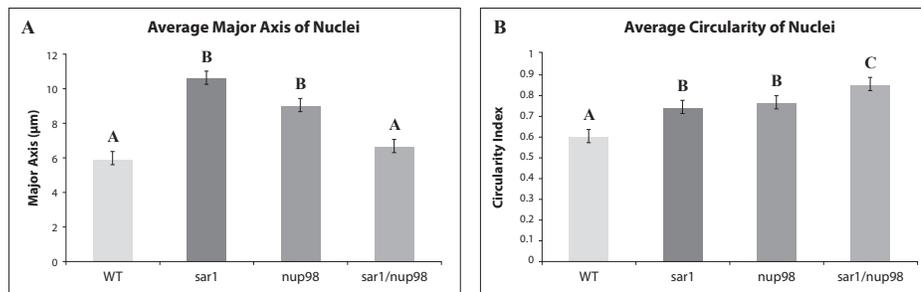
Wild type and *sar1/nup98* nuclei are smaller than *sar1* and *nup98* nuclei, but mutant nuclei are more circular than wild type nuclei.

The major axis and circularity of fixed and imaged nuclei from wild type, *sar1*, *nup98*, and *sar1/nup98* lineages were measured using Image J.

Figure 2 (A) Major axes for wild type, *sar1*, *nup98*, and *sar1/nup98* nuclei are $5.90 \pm 1.83 \mu\text{m}$, $10.56 \pm 2.56 \mu\text{m}$, $8.98 \pm 3.81 \mu\text{m}$, and $6.61 \pm 2.74 \mu\text{m}$ respectively.

(B) Average circularities for wild type, *sar1*, *nup98*, and *sar1/nup98* mutant nuclei were 0.69 ± 0.19 , 0.74 ± 0.12 , 0.76 ± 0.12 , and 0.84 ± 0.15 respectively.

Data are represented in means \pm SE ($n = 30$ for all populations.) "A" designates the control results, "B" indicates a significant difference between the control, and "C" specifies a significant difference between the control as well as between at least one other mutant.



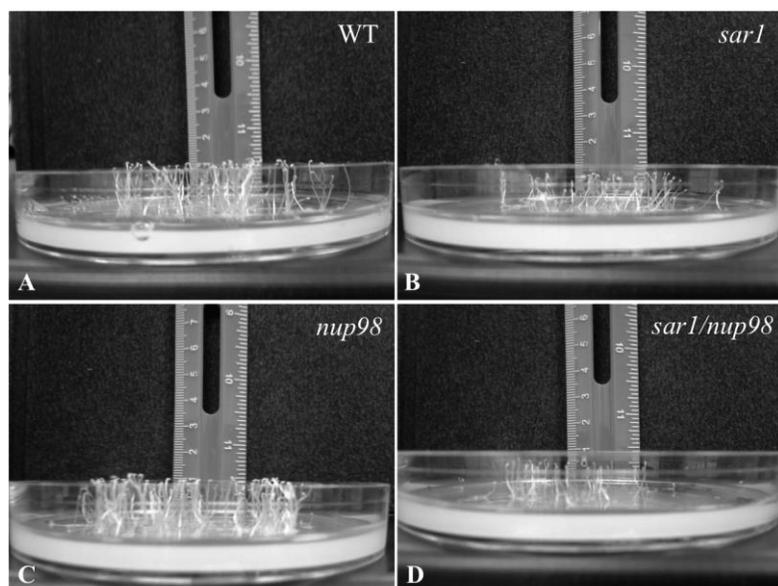
Average major axis lengths and circularities were calculated to determine the shape and size of the nuclei. Longer axis lengths would imply larger-sized nuclei, and a circularity index of 1 would indicate a perfect circle. The average major axis lengths for wild type, *sar1*, *nup98*, and *sar1/nup98* mutant nuclei were $5.90 \pm 1.83 \mu\text{m}$, $10.56 \pm 2.56 \mu\text{m}$, $8.98 \pm 3.81 \mu\text{m}$, and $6.61 \pm 2.74 \mu\text{m}$ respectively. Average circularities for wild type, *sar1*, *nup98*, and *sar1/nup98* mutant nuclei were 0.69 ± 0.19 , 0.74 ± 0.12 , 0.76 ± 0.12 , and 0.84 ± 0.15 respectively (Fig 2).

T-tests were used to test for significance between nuclei populations. P-values for the major axis between wild type versus *sar1*, *nup98*, and *sar1/nup98* respectively were 3.9268×10^{-11} , 0.000131003 , and 0.121320181 . P-values for the circularity between wild type versus *sar1*, *nup98*, and *sar1/nup98* were 0.000713597 , 0.000132972 , and 4.41091×10^{-7} , respectively. An α -level of 0.05 was used. Data suggest that major axes of wild type and *sar1/nup98* nuclei differ significantly from those of mutant nuclei. The major axis length for the wild type and *sar1/nup98* nuclei was shorter, indicating that wild type and *sar1/nup98* nuclei are smaller. The *sar1*, *nup98*, and *sar1/nup98* mutant nuclei were also more circular on average than the wild type nuclei.

Images of hypocotyls for wild type, *sar1*, *nup98*, and *sar1/nup98* plants were taken in order to detect differences between hypocotyl lengths for each lineage. *sar1/nup98* hypocotyls were significantly shorter than those for every other lineage (Fig. 3D).

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Figure 3 *sar1/nup98* hypocotyls in the dark are significantly shorter than those of other lineages.
 Images taken of hypocotyls grown in the dark from: (A) wild type; (B) *sar1*; (C) *nup98* and (D) *sar1/nup98*.

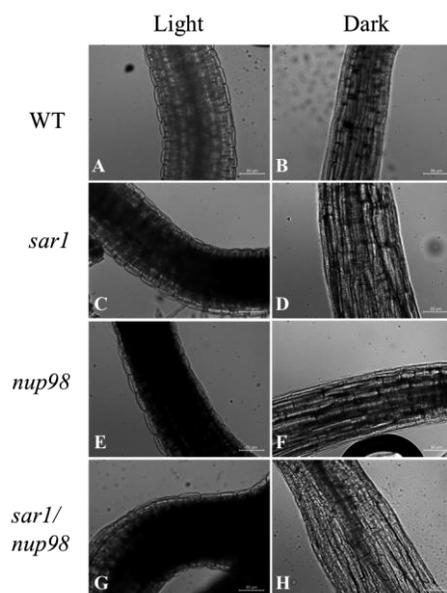


Hypocotyl cells were imaged in order to determine the effect of dark conditions on cell length. Wild type hypocotyl cells have “ridges” on the sides, indicating that more lateral expansion occurs (Fig 4A). *sar1* and *nup98* hypocotyl cells exhibit these ridges as well (Fig 4C, 4E). However, the ridges in *sar1/nup98* hypocotyl cells under light conditions are not discernible, and there is much cell overlap (Fig 4G). Under dark conditions, *sar1/nup98* hypocotyl cells did not align in a single file like wild type and single mutant cells do (Fig 4H).

Average major axis lengths were calculated for cells in the hypocotyl under light and dark conditions in order to determine if *sar1*, *nup98*, and *sar1/nup98* hypocotyl cells elongate in the dark similarly to wild type hypocotyl cells. If another pattern was exhibited, then *sar1* and *nup98* may have had some effect on hypocotyl cell elongation in the dark. The average major axis lengths for wild type, *sar1*, *nup98*, and *sar1/nup98* in the light were $31.87 \pm 10.26 \mu\text{m}$, $34.19 \pm 9.77 \mu\text{m}$, $35.81 \pm 9.34 \mu\text{m}$, and $32.27 \pm 10.05 \mu\text{m}$. The average major axis lengths for wild type, *sar1*, *nup98*, and *sar1/nup98* in the dark were $50.85 \pm 21.42 \mu\text{m}$, $54.14 \pm 28.66 \mu\text{m}$, $51.14 \pm 15.26 \mu\text{m}$, and $54.51 \pm 31.17 \mu\text{m}$. Mutant hypocotyl cells elongated in the dark similarly to wild type hypocotyl cells (Fig 5). Specifically, the percent differences for wild type, *sar1*, *nup98*, and *sar1/nup98* are 45.89%, 45.17%, 35.26%, and 51.26% respectively (Fig. 6).

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Figure 4 Hypocotyl cells from wild type, *sar1*, *nup98*, and *sar1/nup98* mutants.
 Images taken using BF of representative hypocotyl cells from:
 (A) and (B) wild type in light and dark, respectively.
 (C) and (D) *sar1* in light and dark, respectively.
 (E) and (F) *nup98* in light and dark, respectively.
 (G) and (H) *sar1/nup98* in light and dark, respectively.
 Scale = 50 μ m.



T-tests were used to test for significance between the hypocotyl cell populations. There were no significant differences between light treatments for all populations. P-values for the major axes of the wild type light versus *sar1* light, *nup98* light, and *sar1/nup98* light were 0.36906646, 0.079086267, and 0.877240674. There were also no significant differences between dark treatments for all populations. P-values for the major axes of the wild type dark versus *sar1* dark, *nup98* dark, and *sar1/nup98* dark were 0.649252435, 0.960119275, and 0.661127638. P-values for wild type, *sar1*, *nup98*, and *sar1/nup98* light-dark combinations were 0.000435448, 0.002130654, 0.000646326, and 0.005631752. An α -level of 0.05 was used. Data suggest that *sar1*, *nup98*, and *sar1/nup98* hypocotyl cells demonstrate a similar capacity to elongate as wild type hypocotyl cells.

However, the *nup98* mutant has a smaller percent difference, which may indicate that it has less capacity for hypocotyl cell elongation than the other mutants (Fig. 6).

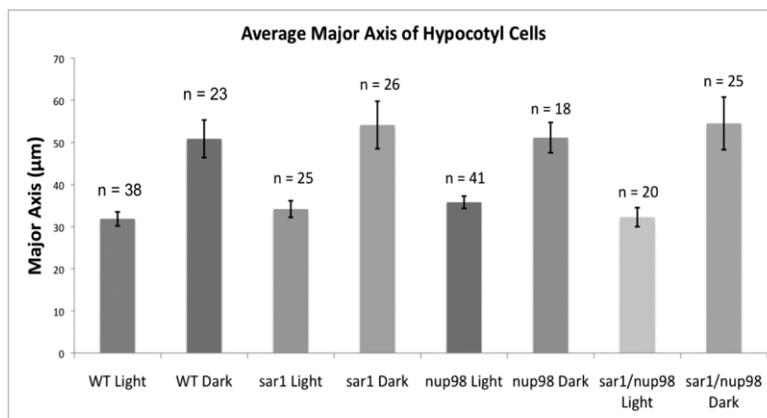
Wild type, sar1, nup98, and sar1/nup98 hypocotyl cells elongate in the darkness.

The major axis of hypocotyl cell from wild type, sar1, nup98, and sar1/nup98 lineages were measured using Image J.

Figure 5

Major axes from left to right are $31.87 \pm 10.26 \mu\text{m}$, $50.85 \pm 21.42 \mu\text{m}$, $34.19 \pm 9.77 \mu\text{m}$, $54.14 \pm 28.66 \mu\text{m}$, $35.81 \pm 9.34 \mu\text{m}$, $51.14 \pm 15.26 \mu\text{m}$, $32.27 \pm 10.05 \mu\text{m}$, and $54.51 \pm 31.71 \mu\text{m}$.

Data is represented in means \pm SE.

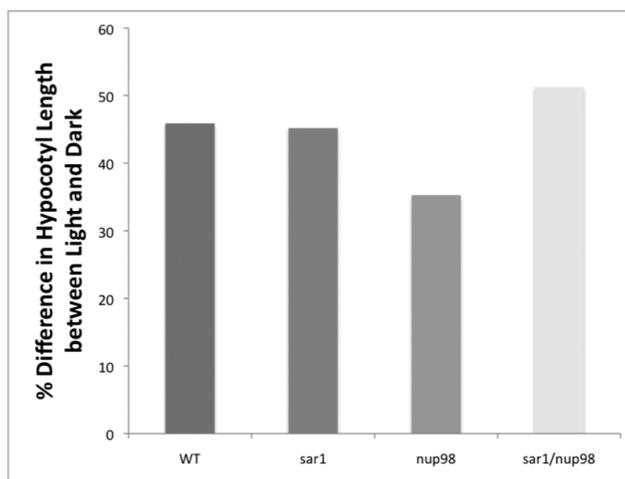


nup98 hypocotyl cells elongate less than those of other lineages.

The percent differences between hypocotyl cell lengths in light and dark conditions were calculated for each lineage.

Figure 6

% differences for wild type, sar1, nup98, and sar1/nup98 are 45.89%, 45.15%, 35.26% and 51.26% respectively.



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Discussion

Nuclei

We are interested in characterizing the nuclear morphology of *sar1*, *nup98*, and *sar1/nup98* mutants in *Arabidopsis thaliana* in order to determine how *sar1* and *nup98* regulate nuclei shape and size. We found that wild type and *sar1/nup98* nuclei were smaller than *sar1* and *nup98* nuclei, but *sar1*, *nup98*, and *sar1/nup98* mutant nuclei were more circular than wild type nuclei (Fig. 2). *sar1/nup98* mutant nuclei were also the same size as wild type nuclei. Previous data from *nup136/nup1* shows that mutant nuclei have shorter major axes and higher circularity indices (Tamura *et al.*, 2010). Circularity results align with these previous results, but size results do not.

Nuclear morphology is dependent on factors such as the cytoskeleton, the nuclear skeleton, and the nuclear lamina (Webster *et al.*, 2012). Single mutant nuclei were most likely larger because the cells lost the ability to regulate the shape and size of their nuclei. For instance, the cytoskeleton is the framework for the cell, so defects in the cytoskeleton could result in abnormal nuclear morphology. If *sar1* and *nup98* interact with the cytoskeleton, then most likely *sar1* and *nup98* mutants would have defects in nuclear morphology as well. The wild type nuclei could also have been smaller because only a subset of the entire population was measured.

In vertebrates, lamins are responsible for the circularity of the nucleus. Plants possess LITTLE NUCLEI (LINC) proteins, which may perform similar functions. Thus, *sar1* and *nup98* may interact with these factors in order to produce wild type nuclear morphology.

The major axis of the nucleolus in mutant versus wild type nuclei could also be measured in order to investigate if *sar1* and *nup98* contribute to nucleolus size. *sar1/nup98* mutant nucleoli were observed to be larger than those of wild type in this particular study.

“Halos” around the nucleus obscured the true outline of the nucleus (Fig. 1B). If decreasing the exposure or using less DAPI reduced these halos, the measurements for major axis lengths and circularity indexes would be more accurate.

Hypocotyls

Arabidopsis hypocotyl cells elongate under dark conditions (Gendreau *et al.*, 1997). Experiments were performed to see if *sar1*, *nup98*, and *sar1/nup98* mutants exhibited the same pattern. *sar1* is involved in the auxin pathway. Auxin is a growth hormone that regulates cell division and cell regulation. Therefore, *sar1*, *nup98*, and *sar1/nup98* mutants might have defects in hypocotyl cell elongation. If *sar1*, *nup98*, and *sar1/nup98* mutants did not exhibit the same pattern as wild type, then most likely *sar1* and *nup98* contribute to hypocotyl cell elongation in the dark. However, *sar1*, *nup98*, and *sar1/nup98* mutants do exhibit the same pattern, so *sar1* and *nup98* do not contribute to hypocotyl cell elongation in the dark.

sar1/nup98 has markedly shorter hypocotyls in the dark than any of the other lineages (Fig. 3D). This may be due to a decrease in the elongation of cells or a decrease in the division of cells. The former hypothesis was tested in this experiment; *sar1*, *nup98*, and *sar1/nup98* mutants exhibit the same behavior in the dark as wild type did, so most likely *sar1* and *nup98* do not affect the capacity of hypocotyl cells to elongate in the dark. *nup98* hypocotyl cells, however, may have less capacity to elongate than those of other mutants (Fig. 6). Ultimately, mutants most likely have fewer cells in the hypocotyl. Since a seedling has a defined set of cells in the hypocotyl during early development, this might point to a defect in embryogenesis. However, the number of cells in the hypocotyl could not be measured because of improper alignment of cells in the double mutant (Fig. 3H). Therefore, a future experiment could be designed to determine if the *sar1/nup98* hypocotyl is shorter due to a decrease in the number of cells.

sar1/sar3 plants exhibited abnormal characteristics such as no pigmentation, severe reduction or absence of leaves and roots, as well as extremely small seedlings. Early flowering was also present. These characteristics are most likely due to accumulation of RNA and improper retention of the Aux/IAA repressor within the nucleus (Parry *et al.*, 2006). *sar3* is a homologue to the vertebrate nucleoporin *nup96*, which is also located within the Nup107-160 subcomplex. In vertebrates, the NUP196 polyprotein is cleaved to produce NUP98 and NUP96. NUP96 and NUP98 have proteolytic motifs at their N and C termini, respectively. Therefore, *sar1/sar3* and *sar1/nup98* most likely would have similar gross physiological phenotypes. *sar1/nup98* may also have defects in RNA transport, so RNA levels in the nucleus could be measured to see if this is the case. Further analyses should be performed to differentiate the function of *sar3* (*nup96*) from that of *nup98*.

Placing *Arabidopsis* seedlings in the light and dark allows for the response of plants to different signals to be measured. For instance, if mutants do not grow as well in the light, most likely there is a defect in the signaling to produce a proper light response. Using different kinds of light such as red or blue light will also produce more information about these effects.

Unclear outlines of hypocotyl cells obscured the count of cells in the hypocotyl (Fig. 3H). For instance, since *sar1/nup98* did not have cells that aligned in a single file under dark conditions, it was particularly hard to determine the number of cells present.

Higher circularity indices in *sar1*, *nup98*, and *sar1/nup98* mutants indicate that *sar1* and *nup98* play a role in regulating and maintaining nuclear morphology. *sar1*, *nup98*, and *sar1/nup98* mutants exhibit hypocotyl cell elongation in the dark similarly to wild type, so they have a similar capacity for elongation as wild type cells. Therefore, *sar1* and *nup98* are necessary for wild type nuclear morphology, but are not required for hypocotyl cell elongation.

Determining how *sar1* and *nup98* regulate hypocotyl elongation through auxin signaling will further our understanding of how nucleoporins contribute to plant growth and

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development. Ultimately, investigating the roles of *sar1* and *nup98* in NPCs will elucidate the basis of nuclear diseases like progeria.

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The Effects of Sibship Size on Intergenerational Occupational Mobility

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Abstract

Several studies have researched people's intergenerational transmission of occupation. In this study, regression analyses are used to investigate the effects of sibship on occupational roles. Using data from a national sample of 12,686 young men and women, who were 14-22 years old when they were first surveyed in 1979, this paper examines whether a child with more siblings will be less likely to follow in his or her parents' footsteps with respect to occupation; it also studies the gender and cultural effects on occupational mobility between generations. There is little evidence of a causal relationship between birth order

and occupational transmission. However, sons with more siblings are less likely to follow in their parents' career footsteps.

The strength of the tie between parent and child outcomes is an interesting characterization of a society, revealing the degree to which inequality is transmitted across the generations and in a broad sense speaking to the notion of equality of opportunity.

Corak and Piraino, 2010

1 Introduction

Intergenerational mobility, as a measure of the change in social status from the parents' to the children's generation, has always been of great interest to economists and social scientists. Such mobility across generations provides a means of measuring equality and opportunities presented in a society (Blanden, Gregg, and Machin, 2005). Under the topic of intergenerational relationships between adult and child outcomes, transmission of earnings and education stands out as the focus of most academic research, but recent studies have moved beyond these two topics to other family characteristics.

Occupation is one major indicator of social status in an industrial society. Understanding occupational mobility is, therefore, important; it shows whether or not children have the tendency to choose jobs different from these of their parents', which signifies a shift in labor force composition. Shifts in labor force composition explain substantial proportions of modern observed earning changes. Low occupation mobility could indicate a self-reinforcing mechanism, which causes poverty to persist and a great disparity in income to emerge. However, if high mobility in occupation is shown, it could be a sign that steps have been taken to break the cycle of inequality. In this paper, the effects of family structure, in particular, sibship size, on occupational transmission across generations are studied.

1.1 Background Information

Since Blau and Duncan's study of the American occupational structure in 1967, research on intergenerational occupational mobility has made significant progress in the past several decades. Tyree and Treas (1974) have found differences in occupational mobility patterns according to gender and labor status. Hauser, *et al.* (1974) has also reported differences in occupational mobility patterns of men and women when controlling for age and race. Rosenfeld (1978) suggests that, as opposed to a father's, a mother's occupation is a much more significant factor in women's intergenerational occupational mobility.

More recent studies have found strong correlations between fathers and sons. Some studies have borrowed the idea of estimating intergenerational measure of "occupations prestige" and "occupational mobility" from sociology. Sons may enter a father's occupation "because of the investments their fathers make in them, because of inheritable aspects of occupation-specific skills that lead sons to have comparative advantages in their father's

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occupations, or because of barriers to movement out of a father's occupation" (Hellerstein and Morrill, 2008). Transition matrices are used to measure the extent of occupational mobility, and the cells of the matrices are determined by the fathers' and the sons' occupations. Occupational mobility is then calculated as the probability of a child entering his or her parent's occupation (Ferrie, 2005). Using the method described above, Ermisch and Francesconi (2002) find intergenerational correlations that range from 0.4 to 0.75 for father-child pairs and from 0.30 to 0.50 for mother-child pairs in the British Household Panel Survey.¹ Hellerstein and Morrill (2008) show that, in recent cohorts, about 30% of sons and 20% of daughters work in the same occupation as their fathers. Therefore, parents are, indeed, good role models for occupational choices made by the younger generation.

Different methods are also used in examining intergenerational mobility in occupation, but the conclusions are similar - there are strong relationships between father and son occupations. Carmichael (2000), using BHPS, and Di Pietro and Urwin (2003), using Italian data, suggest that individual attainment is strongly influenced by parental status, and that the occupational attainment of sons is found to depend significantly on that of their parents, especially their fathers.

A number of very recent papers have moved beyond occupation to see whether children could get jobs in the same firms as their parents (Black and Devereux, 2010).

Besides Perez-Gonzalez (2006) of the United States and Bennedsen (2007) of Denmark, Corak and Piraino (2010) find that "about 40% of a cohort of young Canadian men has been employed at some time with an employer for whom their father also worked, and 6% to 9% have the same employer in adulthood."^{2 3}

1.1.1 Occupational Categories

Like Hellerstein and Morrill (2008), this paper uses three-digit 1980 occupation codes to classify specific occupations, but it does not use a metric of occupational rank or prestige to measure the continuity of parent and child occupation. It emphasizes that occupational structures are highly differentiated by sex, and that some occupations are more likely to

¹ The intergenerational elasticity is around 0.2 for men and between 0.1 and 0.23 for women (Ermisch and Francesconi, 2002).

² Such intergenerational transmission is positively related to paternal earnings, particularly at the very top of the earnings distribution, and to the presence of self-employment income and the number of employers with which the father has had direct contact (Corak and Piraino, 2010).

³ The interaction between parents' employment and children's employment are further explored in Kramarz and Skans (2007), which uses a Swedish population-wide linked employer-employee data set to show that a plant is more likely to hire one of its employees' children than someone else from the same class. In particular, "the father is central for sons when the mother is useful for daughters, [and] children trained in the same field of study as their father or their mother are more likely to benefit from referral hiring" (Kramarz and Skans, 2007).

attract and/or be filled by one sex than the other, so distinct occupational categories are created.

1.1.2 Like Father Like Son

Correlations between fathers and sons have been found in recent studies. In addition to the sole father-son relationship, this paper tests all possible combinations between parents and children, including father-son, father-daughter, mother-son, and mother-daughter. Moreover, it tests whether either parent's occupation (one or both) has an important effect on a child's occupation.

1.1.3 Sibship Size

Unlike the other papers mentioned above, this paper focuses on the effect of sibling composition, in particular sibship size, on intergenerational occupational mobility. The number of siblings is correlated with birth order (Bavel, Moreels, Van de Putte, and Matthijs, 2011). People with one or two siblings cannot have birth order six or seven, and first-born children are more likely to be found among families with one or two children than among bigger families. As a consequence, if birth order has an effect on occupational choices, such effect may have already been captured by sibship size.

1.2 Models of Sibling Composition

Several models have been developed in the past to illustrate intergenerational occupational mobility. Here, I argue that parental time investment and job-specific human capital investment can offer an explanation for a child following in parents' occupational footsteps.

Parents play an important role in individual's development by "shaping needs and values; by providing positive and negative role models for play and interpersonal relations; and finally by providing resources for implementation of the individual's self-concept – resources of information, contacts and money" (Super, 1957). The time and financial resources parents invest in their children affect many aspects of the young generation, including their vocational development.

1.2.1 Time Investment

Each person has a limited amount of time to be allocated among daily activities. Besides work and leisure, parents tend to spend some time with their children every day and assure that they have the proper mental and physical development through adolescence. A British study finds that working mothers devote 81 minutes to their children daily, and fathers spend less time than mothers looking after their offspring (Lewis, 2007). Older children would naturally spend more time with their parents, because they are born earlier. In other words, holding all else fixed, the amount of time parents invest in these children

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is larger because of birth order. So, being the first born of the family, he or she would be living under his or her parent(s) influence for the longest time. Moreover, children with no siblings may receive the benefit of solely enjoying the time with his or her closest role models.

1.2.2 Financial Investment

In addition to the constraint of time, each family also has limited financial resources. The parent(s) chooses the amount of the consumption good to purchase and the amount of investment to make in his or her children's general human capital and job-specific human capital. In particular, such investments in human capital are specific to one or both parent(s) occupation, causing a rise in the probability that a child enters his or her parent(s) occupation. When the family has more than one child, the family income, less the basic necessities, has to be divided among several children, so the smaller number of siblings one has, the more likely he or she will get a bigger portion of such family investment in his or her human capital. Moreover, the family income is not evenly divided among children, so the earlier-born ones have the advantage to enjoy the rather abundant resources than the later-born ones. Since such resources could have already been exhausted, and no more human capital, especially job-specific human capital, can be afforded, the younger siblings would have a smaller probability of entering their parent(s) occupation due to lack of needed education and investment.

1.3 Research Questions

Based on the model established above, questions concerning intergenerational occupational mobility are further investigated in this paper:

- How do family structure and demographics affect intergenerational occupational mobility?
- Will a child with more siblings be less likely to follow in his or her parents' career footsteps?

2 Data

This paper utilizes a demographic database called NLSY79 provided by the Bureau of Labor Statistics. This database contains data from a nationally representative sample of 12,686 young men and women ages 14-22 years old when they were first surveyed in 1979. During the years since that first interview, these young people typically have finished their schooling, moved out of their parents' homes, made decisions on continuing education and training, entered the labor market, served in the military, married, and started families of their own. For each NLSY79 household surveyed, data were collected on every eligible

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individual aged 14 to 21, who resided in the household at the end of 1978. Each respondent provided general information on family background, educational attainment, and labor force status.

Under the section of family background and demographic characteristics, selected surveys have collected information on respondents' gender, racial/ethnic identification, and number of siblings. (1) The original data has classified race into three groups, Nonblack/Non-Hispanic, Black, and Hispanic. For simplicity, binary variable, "Race," is created to indicate if a respondent is Nonblack/Non-Hispanic or the two minorities mentioned above. (2) Income sources identified include the respondents' and their spouses' or partners' wage and salaries, income from military service, profits from a farm or business, Social Security, pensions and annuities, and alimony/child support. The data collected showed the total income received by every family member living in the household. The variable is modified as "log(income)" and used in the full regression model in section 4.3 of this paper. (3) The raw data show that the modal number of siblings is two, and respondents' answers range from zero siblings to 29.

The majority of parental information was collected in the 1979 survey. However, a significant amount of data is legitimately missing; in particular, 28 respondents stated that they never knew their mother and 230 stated that they never knew their father. For those who are able to answer questions about their parents, mother's and father's highest grade completed and occupational information are collected.

Table 1 and 2 show the name of occupational categories and frequencies of being in each category by gender; the information on occupation is readily available for all respondents on their current labor force status. Both parents and children, who have reported being employed, are asked to supply job- and company-specific data, such as occupation and industry; the occupational information are grouped into 12 distinct categories, which is further reduced to 6 in the later research.

3 Data Coding and Variable Creation

Binary variables are created to indicate whether or not parents' and children's occupations match. Moreover, an additional binary variable is created to indicate if children's occupation matches with, at least, one of his or her parents'. Table 3 provides descriptive statistics for each of the binary variables. In general, respondents have a higher tendency of following in their mothers' career path as it is indicated in the second column. 20.37% of children follow in their fathers' footsteps, and 28.42% of them follow in their mothers' career pathways. About 8% of a difference can be seen in the twelve-category set, and 6.5% difference is found in the six-category set. When gender is specified, the same trend follows as it is seen in column 3 and 4 of Table 3. However, when comparing the results horizontally within each category (all, daughter, and son), children's occupation generally does not match with their parent(s)'. 59.02% of children do not follow in their

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parents' footsteps in the twelve-category sample and 53.28% do not follow in the six-category sample.⁴

Several control variables are created to control the "large category effect." As it is seen in Table 1, a large percentage of females (mothers) become service workers (24.11%), clericals (23.64%), and operatives (20.29%). At the same time, large percentages of males (fathers) work as craftsmen (24.95%), operatives (20.13%), and professionals (11.34%). Therefore, certain occupational categories are simply more likely to be chosen, because they tend to be gender-specific. In other words, a son is more likely to follow in his father's footsteps if his father's occupational category is more common than the others. In order to take into consideration of the fact that some categories are bigger than the others, parent's occupation frequencies from Table 1 are borrowed to predict the probability of being in specific occupation. Specifically, father's occupational frequencies are used to predict sons' outcomes, and mother's occupational frequencies are used for predict daughters'. For example, a boy is predicted to have a probability of 20.13% of becoming an operative, and a girl is predicted to have a probability of 24.11% of becoming a service worker. Moreover, the variable "Son in Mother's Occupation" indicates the probability that a boy will enter a specific occupation when his mother is in that occupation, and the variable "Daughter in Father's Occupation" indicates the probability that a girl will enter a specific occupation when her father is in that occupation. Male and female frequencies are again used in predictions. For instance, a boy, whose mother is a sales worker, has a probability of 4.48% of working in the same occupation; a girl, whose father is a farmer, has a probability of 2.33% of becoming a farm girl.

Analogously, control variables are created for the dependent variable that indicates if children's occupation matches with either one of his or her parents'; the coding is different from the variables above, because, now, both parents' occupations are considered. Father's occupational frequencies are again used to predict boys' outcomes, and mother's occupational frequencies are used to predict girls', but it involves adding these probabilities when parents are in different occupational categories and preserving the original probability when the parents are in the same category. For example, if the respondent is a boy, his likelihood of being in either group 2 or group 3 when his parents are in such groups is the sum of 12.32% and 4.48%, which is 16.8% in the twelve-category set, taking the probabilities from male's frequencies. If the respondent is a girl, her likelihood of being in either group 4 or group 5 when her parents are in such groups is the sum of 23.64% and 2.36%, which is 26% in the same set of data, taking the probabilities from female's frequencies. To name the variables, "Daughter-Control," which uses the mother's occupational frequencies,

4 Under the twelve-category classification, based on the female frequency, a daughter has a probability of 17.75% to randomly enter her mother's occupation, compared with the statistical result of 29.75%. Based on the male frequency, a son has a probability of 14.65% to randomly enter his father's occupation, compared with the statistical result of 21.90%.

indicates the likelihood of a girl in one of the two categories that her parents are in, and “Son-Control,” which uses the father’s occupational frequencies, shows the likelihood for a boy.

4 Regressions

This section is broken into four parts. Sections 4.1 and 4.2 examine the effects of birth order and number of siblings on the binary dependent variables overall and broken down by gender. Section 4.3 shows the full regressions when other explanatory variables are used. In this section, cultural inheritance is partially tested by variables “gender” and “race.” Additional regressions are conducted on testing the effects of being the first-born and/or only child in the family; results are reported in section 4.4. In each section, control variables are always used to manage the “large category effect,” and they have been shown to be statistically significant.

4.1 Parent-Child Model

Letting the subscript, 12 , denote the twelve-category set, I consider the following models for testing the parent-children transmission:

$$I_{12} = \text{Daughter-Control} + \text{Son-Control} + \alpha \text{NumSib} + \beta \text{BirthOrd} + \epsilon$$

In general, the variable “number of siblings” has a negative effect on the dependent variables, which means that having more siblings will reduce the chance of following in parent’s footsteps. As seen in Table 4, having one more sibling will reduce one’s chance of pursuing the same career with father by 0.51%. The negative estimate is not statistically significant for mother-child transmission. Having one more sibling reduces a daughter’s chance of following in her father’s footsteps by 0.38% and a son’s chance by 0.64%; both results are statistically significant.

An analogous model for the six-category set, with subscript 6 denoting number of categories, is given by:

$$I_6 = \text{Daughter-Control} + \text{Son-Control} + \alpha \text{NumSib} + \beta \text{BirthOrd} + \epsilon$$

As seen in Table 4, having one more siblings will reduce one’s chance of pursuing the same career with his or her mother by 0.30% and father by 0.70%. In the results broken down by gender, a boy with an extra sibling will reduce his chance of following in his father’s footsteps by 1.2%.

Regardless of which set of data is used in regressions, the effect of number of siblings

on boys is more significant than it is for girls. Moreover, larger effects for both sons and daughters are found in the following-father regressions.

4.2 Either Parent-Child Model

The same general estimation strategy for the either-parent occupation variable is used as follows:

$$I = \text{Daughter-Control} + \text{Son-Control} + \alpha \text{NumSib} + \beta \text{BirthOrd} + \epsilon$$

As it is seen in table 5, when gender is not specified, having one more sibling will reduce a child's chance of following either of the parents by 0.82% in the twelve-category set and by 1.05% in the six-category set. Both results are statistically significant. However, when gender is specified, the result is not significant for females. For males, a 1.05% reduction for the twelve-category set and 1.26% reduction for the six-category set can be seen from the last column of Table 5.

The other variable of interest, birth order, is not a significant determinant of the dependent variables. In Black (2005), it has been suggested that family size itself has little impact on the quality of each child in terms of educational attainment but more likely impacts only the marginal children through the effect of birth order. In the NLSY results, such an effect does not show up in the intergenerational transmission of occupation.

4.3 Full Regression Model

Aside from the variables of interest, "Number of siblings" and "Birth Order," other variables are used in the full regression model; they include family income, parent's education, gender, and race. The model is given by:

$$I = \text{Daughter-Control} + \text{Son-Control} + \alpha \text{NumSib} + \beta \text{BirthOrd} + \varphi \text{Log}(\text{inc}) \\ + \lambda \text{MomEdu} + \mu \text{DadEdu} + \Theta \text{Gender} + \sigma \text{Race} + \epsilon$$

Impact of the newly added variables: After several other explanatory variables are added to the either parent-child model, variable "Number of Siblings" loses the original significant effect on the dependent variables. As seen in Table 6, the negative direction is preserved, but the p-value increases. When gender is specified, having one more sibling would reduce a boy's chance of following either of his parents by 1.05%.

Impact of Human Capital: There have been several research studies showing that parents with higher education levels have children with higher education levels. If such a theory were true, for parent(s) with a specific occupation, such as legal or medical practitioners that generally requires more education, their children would have a high

probability of getting more education, compared to children whose parents are college dropouts, due to family characteristics and inherited ability.

Parents' education also has significant effects on intergenerational transmission of occupation. The more education each or both parents have, the more likely their children are to enter the same profession as them. Increasing mother's education by one year would increase one's chance of following in either of the parents' footsteps by 0.73%, and one more year added on father's education would raise the chance of intergenerational transmission of occupation by 0.43%. When gender is specified, the last two columns of table 6 show that for a girl, the parents' education has a bigger influence on her career choice, as compared with the general case. However, for a boy, such effects are reduced.

Cultural inheritance: In the past research, it has been shown that cultural inheritance plays a causal role in intergenerational occupational correlation between the mother and daughter. In contrast, there is no robust evidence that cultural inheritance is important for a sons' occupation choice (Emran, Shilpi 2008). "Race" and "Gender" are the two variables that are used to reflect the possibility of cultural inheritance in this paper, and they both show significantly positive effects on the dependent variable. Specifically, being a minority would increase a child's probability of following either of his or her parents by 4.82%, and being a woman would increase the same figure by 7.29%.

When gender is specified, a minority female would be 3.87% more likely to follow in her parent(s)' footsteps, and a minority male would be 5.61% more likely on the same figure. One explanation is that sex- and race-based differences in socio-economic status persist, and interaction between gender and class and between race and class continue to play a role in the intergenerational transmission of income (Kearney, 2006), which is guarded by occupation. If minority children are more likely to follow in their parent' footsteps, these children are much more likely to remain in the lower percentiles of the income distribution, because mean income is lower among minorities than among whites. Therefore, historical and cultural inheritance, such as differences in occupation, is one of the reasons that the transmission of income class from parents to children differs noticeably among racial groups.

The same types of effects have been shown in the six-category set; however, there are several distinct effects that are only found in this categorization.

Income: "Family income," represented by the log of income, does not come out as a significant variable in the previous regression. However, when the number of categories is reduced and, at the same time, gender is specified, income plays an interesting role in influencing a girl's chance of following her parent(s)' footsteps. On the second part of Table 6, it is shown that increasing family income would actually decrease the possibility of transmission of occupation, which creates hope for women to become more mobile on job-taking since it has been shown that they are more likely to enter the occupation their parents have chosen. As discussed above, sex-based differences in economic standings

do persist; higher level of family income could provide a girl with the necessary financial resources she needs to move upward on the socioeconomic ladder and to lead American women, at least the younger generation, to move out of the circle of occupations they might have been trapped in.

Number of Siblings: After some occupational categories are combined, “number of siblings” has shown some minor effect, in general, on vocational transmission. Having one more sibling would reduce a child’s chance of following his or her parent(s)’ footsteps by 0.80%. When gender is specified, being a boy would reduce the same figure by 1.32%.

4.4 First-born and/or Only Child?⁵

In the hypothesis, it is expected to see that being the first-born (birth order) and/or only child (number of siblings) would each have a significant positive effect on any of the dependent variables, because parents would have been the role models for the first child for the longest time in life, and there is no other sibling trying to “distract” the only kid from following in his or her parent(s)’ footsteps. However, the results did not come out the way as anticipated. Aside from the assumed positive direction, none of them came out statistically significant, regardless of the general case or when gender is specified.

The regression models are set up as the following:⁶

$$I = \text{Daughter-Control} + \text{Son-Control} + \gamma\text{FirstBorn} + \eta\text{OnlyChild} + \epsilon$$

An analogous model for the six-category set is tested; no significant result is obtained.

5 Conclusions

In this paper, I have shown that both family structure and demographic characteristics are significant dimensions of intergenerational occupational mobility. Even though, there is little evidence of a causal relationship between being the only child or first born and occupational transmissions, sons with more siblings are less likely to follow in their parents’ footsteps. Moreover, human capital, cultural inheritance, and family income have played interesting and significant roles on intergenerational occupational mobility. Women and minorities might have been trapped with relatively lower economic status due to lack of necessary mobility; these specific groups are expected to move upward on nation’s socio-economic ladder by getting higher education and more financial resources. As one

⁵ These two binary variables are derived from “birth order” and “number of siblings.”

⁶ Variables “First-born” and “Only-Child” are also used in full regressions; however, the results are not statistically significant.

drawback to this study, the effects of family structure on occupational transmission are complicated by the endogeneity of family size. Families with more children are different in many unobservable ways. The dataset, NLSY79, does not provide enough data to deal with this problem. Further work needs to address this issue of endogeneity, focusing on the differential impact by family background.

Table 1 | *Original Occupational Categories and Frequencies⁷*

Group#	Occupation Categories	Female Frequency	Male Frequency
1	Professional, Technical and kindred	11.96	11.34
2	Managers, Officials and Proprietors	3.97	12.32
3	Sales Workers	4.33	4.48
4	Clerical and kindred	23.64	4.15
5	Craftsmen, Foreman, and kindred	2.36	24.95
6	Armed Forces	0.08	2.72
7	Operatives and kindred	20.29	20.13
8	Laborers, except Farm	0.97	6.58
9	Farmers and Farm Managers	0.15	2.93
10	Farm Laborers and Foreman	2.33	3.31
11	Service Workers except Private Household	24.11	7.05
12	Private Household	5.82	0.02

Table 2 | *Combined Occupational Categories*

Group#	Occupation Categories	Female Frequency	Male Frequency
1	Professionals and Officials (Group 1&2)	15.93	23.66
2	Sales and Clerical (Group 3&4)	27.97	8.64
3	Craftsmen, Foreman (Group 5)	2.36	24.95
4	Clerical and kindred	0.08	2.72
5	Laborers, including Farm Labors (Group 7-10)	23.74	32.96
6	Service Workers, Including Private Household	29.92	7.07

7 Consistent 3-digit occupational codes are provided in Appendix.

Table 3 | Likelihood that a Child Has the Same Occupation as Parent(s)

12-Category Classification	All	Daughter	Son
Child follows Mother	28.42%	29.75%	27.14%
Child follows Father	20.37%	28.81%	21.90%
Child follows Either	40.98%	40.39%	41.56%
6-Category Classification	All	Daughter	Son
Child follows Mother	31.11%	32.21%	30.03%
Child follows Father	24.88%	22.7%	27.02%
Child follows Either	46.72%	45.57%	47.85%

Table 4 | Regressions Analysis for the Likelihood that a Child Has the Same Occupation as Parent(s)⁸⁹

12-Category Classification						
Explanatory Variables	Mother-Child			Father-Child		
	All	Daughter	Son	All	Daughter	Son
	-0.0016	-0.0001	-0.0035	-0.0052**	-0.0038*	-0.0064**
Number of Siblings	(0.0027)	(0.0045)	(0.0031)	(0.0018)	(0.0022)	(0.0028)
	-0.0016	-0.0046	0.0014	0.0033	-0.0009	0.0056
Birth Order	(0.0091)	(0.0177)	(0.0102)	(0.0022)	(0.0028)	(0.0034)
6-Category Classification						
Explanatory Variables	Mother-Child			Father-Child		
	All	Daughter	Son	All	Daughter	Son
	-0.0030**	0.0011	-0.0056	-0.0070***	-0.0021	-0.0119***
Number of Siblings	(0.0033)	(0.0050)	(0.0041)	(0.0023)	(0.0032)	(0.0034)
	-0.0004	-0.0021	0.0008	0.0031	-0.0014	0.0075
Birth Order	(0.0037)	(0.0341)	(0.0047)	(0.0028)	(0.0037)	(0.0418)

8 Control variables, “Daughter-Control” and “Son-Control,” are used but not reported in the table.

9 Single asterisk means the p-value is less than 0.1; double asterisk means the p-value is less than 0.05; triple asterisk means the p-value is less than 0.01.

Table 5 | *Regressions Analysis for the Likelihood that a Child Has the Same Occupation as Either Parent*^{10 11}

12-Category Classification			
Explanatory Variables	Either Parent-Child		
	All	Daughter	Son
Number of Siblings	- 0.0082** (- 0.0039)	- 0.0068 (0.0056)	- 0.0105** (0.0053)
Birth Order	0.0011 (0.0046)	- 0.0052 (0.0064)	0.008 (0.0231)

6-Category Classification			
Explanatory Variables	Either Parent-Child		
	All	Daughter	Son
Number of Siblings	- 0.0105** (0.0045)	- 0.0088 (0.0065)	- 0.0126** (0.0063)
Birth Order	0.0034 (0.0053)	- 0.0012 (0.2539)	0.0085 (0.0296)

10 Control variables, “Daughter-Control” and “Son-Control,” are used but not reported in the table.

11 Single asterisk means the p-value is less than 0.1; double asterisk means the p-value

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Table 6 | *Regressions Analysis for the Likelihood that a Child Has the Same Occupation as Either Parent(s) with Other Variables¹²*

12-Category Classification			
Explanatory Variables	Either Parent-Child		
	All	Daughter	Son
Daughter-Control	0.0016** (0.0007)	0.0015** (0.0007)	
Son-Control	0.0051*** (0.0008)		0.0051*** (0.0008)
Log (Income)	-0.0116 (0.0010)	-0.0131 (0.0133)	-0.0106 (0.0151)
Mother's Education	0.0073** (0.0017)	0.0094*** (0.0028)	0.0059*** (0.0022)
Father's Education	0.0043*** (0.0014)	0.0057*** (0.0019)	0.0027 (0.0019)
Number of Siblings	-0.0053 (0.0039)	-0.0011 (0.0057)	-0.0105* (0.0055)
Birth Order	0.0024 (0.0046)	-0.0048 (0.0063)	0.011 (0.0065)
Non-White	0.0481*** (0.0130)	0.0387** (0.0185)	0.0561*** (0.0183)
Female	0.0729*** (0.0256)		

6-Category Classification			
Explanatory Variables	Either Parent-Child		
	All	Daughter	Son
Daughter-Control	0.0011 (0.0007)	0.0012* (0.0007)	
Son-Control	0.0049*** (-0.0008)		0.0047 (0.0008)
Log (Income)	-0.0127 (0.0113)	-0.0284* (0.0156)	0.0062 (0.1657)
Mother's Education	0.0041** (0.0020)	0.0054* (0.0032)	0.0038 (0.0026)
Father's Education	0.0080*** (0.0015)	0.0102*** (0.0022)	0.0055** (0.0022)
Number of Siblings	-0.0080* (0.0046)	-0.0034 (0.0066)	-0.0132** (0.0065)
Birth Order	0.0053 (0.0053)	-0.0001 (0.0073)	0.1168 (0.0077)
Non-White	0.0636*** (0.0150)	0.0455** (0.0207)	0.0794*** (0.0215)
Female	0.0969*** (0.0361)		

¹² Single asterisk means the p-value is less than 0.1; double asterisk means the p-value is less than 0.05; triple asterisk means the p-value is less than 0.01.

Appendix | **Occupational Codes**

Group#	Original Code	Occupation Categories
1	1-195	Professional, Technical and kindred
2	201-245	Managers, Officials and Proprietors
3	260-285	Sales Workers
4	301-395	Clerical and kindred
5	401-575	Craftsmen, Foreman, and kindred
6	580-590	Armed Forces
7	601-715	Operatives and kindred
8	740-785	Laborers, except Farm
9	801-802	Farmers and Farm Managers
10	821-824	Farm Laborers and Foreman
11	901-965	Service Workers except Private Household
12	980-984	Private Household
1	1-245	Professionals and Officials
2	260-395	Sales and Clerical
3	401-575	Craftsmen, Foreman
4	580-590	Armed Forces
5	601-824	Laborers, including Farm Labors
6	901-984	Service Workers, Including Private Household

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