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Costs of Group Locomotion: How Infant-carrying and Group Members Mediate Walking Speed Decisions in North American and East African Populations

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COSTS OF GROUP LOCOMOTION: HOW INFANT-CARRYING AND GROUP MEMBERS MEDIATE WALKING SPEED DECISIONS IN NORTH AMERICAN AND EAST AFRICAN POPULATIONS

by

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ABSTRACT

A major portion of humans' activity-based energy expenditure is taken up by locomotion, particularly walking. Humans can offset the energetic expenditure of walking in numerous ways, both evolutionary (such as changes in body shape) and culturally. Behaviorally, people can choose to walk in a variety of ways, including alone or with a group, carrying loads, and walking quickly or more slowly. All of these behaviors have energetic outcomes and as such can be important windows into how populations and groups adjust to different constraints. While sex differences in speed of paired walkers have been established by others, the dynamics of how walkers adjust their speed in more varied groups and in groups containing children remains unexplored. Furthermore, little ecological data exists to illustrate the relationships between walking speed and child-carrying. Because the determinants of group dynamics and parental investment are partially cultural, the present study examines walking behavior between populations in the Northwestern United States and Central Uganda. We recorded the speed, load carriage, and group composition of pedestrians in urban areas of each location. Our data suggest that children are treated fundamentally differently than other loads or walking partners, and that speed adjustments are child-dependent. Sexual division of labor was also observed, with women being much more likely than men to carry children in both cultures. However, clear distinctions between the groups make large generalizations about walking behavior difficult, and highlight the importance of culturally specific contexts.

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INTRODUCTION

The emergence of bipedalism in the human lineage presented new options for optimizing the costs of locomotion. While the energetic benefit of bipedalism is not believed to be a driving factor of its evolution, the efficiency of bipedalism would nevertheless have been strongly selected for after its emergence (Steudel, 1994). Ancient hunter-gatherer populations who traveled far distances for foraging and hunting faced pressures for decreasing the costs of their journeys. Time and energy spent on walking takes away from energy available for reproduction and investment in social groups (Pollard and Blumstein, 2008; Wall-Scheffler and Meyers, 2013). Optimization of locomotor costs then, significantly impacts feeding, foraging, avoiding predators, and reproducing. The cost of locomotion has been shown to depend on morphological as well as behavioral conditions. For example, increases in body size and limb length are associated with decreased locomotor cost (Pontzer, 2007, Steudel, 1994). Additionally, males (i.e. bigger individuals with longer lower limbs) walk at faster speeds than females across different populations (Costa 2010). Behaviors, such as load carrying and walking in groups, also impact the costs and decisions associated with walking and can potentially offer additional selection pressures to just single-person free walking (Boles, 1981; Schepens, Bastein, and Willems, 2016; Wagnild and Wall-Scheffler, 2013).

Like many mammals, human walking shows a speed at which energy expenditure is lower than all other speeds-- as demonstrated by the curvilinear relationship between cost of transport (metabolic cost for a given distance) and speed (Bertram 2005; di Prampero 1986). Thus, when walking alone, humans are expected to prefer speeds which minimize costs under particular conditions. Group walking speed is one parameter that has been shown to override simply energetic choices. Boles (1981) and Costa (2010) show speed changes related to group size and composition in an ecological setting. Dyads walk more slowly than individuals, since one member must adjust for the slower speed of their partner (Boles, 1981). Wagnild and Wall-Scheffler (2013) suggest that these adjustments are based on sex and relationship between walkers. While male and female friends walking together each adjust their speed from the optimum velocity, the same does not hold true for individuals that share romantic relationship. In romantic partners, the male partner will walk more slowly than his preferred speed in order to match female's speed. Wagnild and Wall-Scheffler suggest that the female reproductive system's increased sensitivity to energetic imbalances contributes to males electing to compromise their speed for females in whom they are reproductively invested. When males walk with other males, their speeds tend to increase (Costa, 2010; Wagnild and Wall-Scheffler, 2013). Social phenomena such as the greater degree of social hierarchy in male groups and male aversion to showing same-sex intimacy have been thought to explain this observation (Costa, 2010). The relationships between sex and group walking speed hold true for triads as well as dyads, but the effects have been shown to decrease for groups greater than three individuals (Costa, 2009).

Load-bearing is another behavior which greatly impacts locomotor costs. The net metabolic power of walking has been shown to depend on load, suggesting that a unit of load mass is more expensive to transport than a unit of body mass (Kramer, 2004; Schepens, Bastien, and Willems, 2005). Optimal walking speeds tend to decrease with increasing load size (Schepens, Bastien, and Willems, 2005). Groups of East African women, though, have been shown to carry loads up to 20% of their body mass without increased costs (Maloiy, Heglund, Prager, Cavagna, and Taylor, 1986). Effectiveness of carrying a load seems to depend on its position. Generally, loads add less metabolic cost the closer they are carried to the torso, particularly on the back (Abe, Yanagawa, and Niihata, 2003; Watson, Payne, Chamberlain, Jones, and Sellers 2007, though see Wall-Scheffler and Myers 2013 for the low cost of carrying on the front).

The carriage of children is a special case of load bearing. While regular carriage of heavy food or goods applies only to human primates, child loads are common across species. Particularly for mammalian species, care and transport of offspring during lactation presents enormous energetic costs for one parent, often the mother (Ross, 2001; Kramer, 2004). Despite the apparent metabolic costs of carrying infants, it remains a widespread strategy across mammals. (Rhinegold and Keen, 1963). Amongst primates, infants either "ride" on parents' fur or are transported orally (Ross, 2001). Ross (2001) argues that fur riding has evolved independently and been conserved more than five times in primates. Riding species have longer gestation times, fewer young per litter, and larger group sizes than nonriders, suggesting that riding may be associated with decreased infant mortality. While maternal carrying remains the dominant practice, many New World Monkey fathers, as well as dominant male baboons, also carry infants (Rhinegold and Keen, 1963).

Non-human primate infants are typically carried on the mother's back or front, often relying on the infant's grip. In humans, however, carriage relies on the parents without help from the child's grip (Rhinegold and Keen, 1963). Though ecological data on human infant-carrying is limited, Rhinegold and Keen (1963) found that, in an American urban center, women carried infants more often than men (58.6%; 320/546), but that older children were more likely carried by men. Though back loads are less metabolically costly, they observed most infants being carried on the side (Abe et al., 2003; Rhinegold and Keen, 1963). Side carrying allows accessible interaction between child and parent (Sallstrom and Wall-Scheffler, 2012).

Humans' speed decisions when walking with others and carrying children provides insight into the adaptive value of social relationships. Understanding the circumstances under which people deviate from their optimum speeds reveals the energy tradeoffs people engage in. However, the dynamics of how walkers adjust their speed in varied groups and in groups containing children remains unexplored. Furthermore, little ecological data exists to illustrate the relationships between walking speed and child-carrying. Because the determinants of group dynamics and parental investment are partially cultural, the present study examines walking behavior between populations in the Northwestern United States and Central Uganda. We hypothesize that, across cultures, walking with or carrying children will result in significant walking speed changes compared to walking with adults or carrying comparable loads of food or goods.

METHODS

Subjects

A total of 1,721 subjects were observed in metropolitan public areas walking alongside roads. 969 subjects (355 male and 614 female) were observed in Central Uganda and 752 subjects (337 male and 415 female) were observed in Washington State, U.S.. Only subjects observed purposefully walking toward a destination (i.e. not for exercise) were included. All procedures were approved by Seattle Pacific University's IRB Committee.

Procedure

From a removed viewing location, an observer recorded the subject's speed as the time taken to walk between pre-measured stationary points. The observer recorded the sex and general age category of the subject (child, teenager, adult, or grandparent). Any loads carried by the subject were categorized by **type** (child, food, goods, or stroller), **position** (front, back, side, or shoulder), and **size** (small, medium, or large) of loads carried by the subject. A small load was a purse or a small bag in the hands; a medium load was torso-sized bag such as a backpack; a large load was an oversized bag.

When the load carried was a human child, the relative age category (infant, toddler, or child) of the child was recorded. These related to the size of the loads by infants being medium loads and toddler and children being large loads. Finally, the observer recorded the sex and age group of any party members accompanying the subject. When adults were observed walking in groups, the observer chose a group member at random as the focal figure for data collection. Children were selected as the focal figure only when walking alone or in groups of only children.

In both locations, subjects were observed walking in central “errand running” areas nearby grocery stores and shopping centers over flat ground. Both areas had wide, beside-roadway paths such that subjects could comfortably walk abreast in groups. In the United States, subjects walked on paved concrete, while Ugandan subjects walked on packed, smooth dirt. All data were collected in the early or middle afternoon. Weather conditions during each observation period were also recorded.

Data Analysis

Data were analyzed using SPSS Statistics via a univariate general linear model. Data were split into separate outputs by location when analyzing effects within a population. Walker sex, type of load carried, group composition, number of group members, and the presence of children in the group were tested as fixed factors against the dependent variable of walker speed.

RESULTS

The effects of the type of load carried, the presence of children, composition of the group, and the size of groups on walking speed each differ significantly between people walking in Central Uganda and people walking in the West Coast United States ($p<0.001$). On average, Ugandans walked faster than Americans ($p<0.01$). However, while Ugandans walking alone walked faster than Americans walking alone, Ugandan walkers in groups were slower than both American groups and individual Ugandans (Fig. 1, $p<0.001$). In Uganda, speed decreased with group size, while speed increased with group size in America (Fig. 1, $p<0.001$ for both). Sixty-eight percent (663/969) of Ugandans walked alone, as did 73% of Americans (551/752). Men walked faster than women in Uganda ($p<0.01$), while American men and women walked at about the same speeds ($p=0.411$).

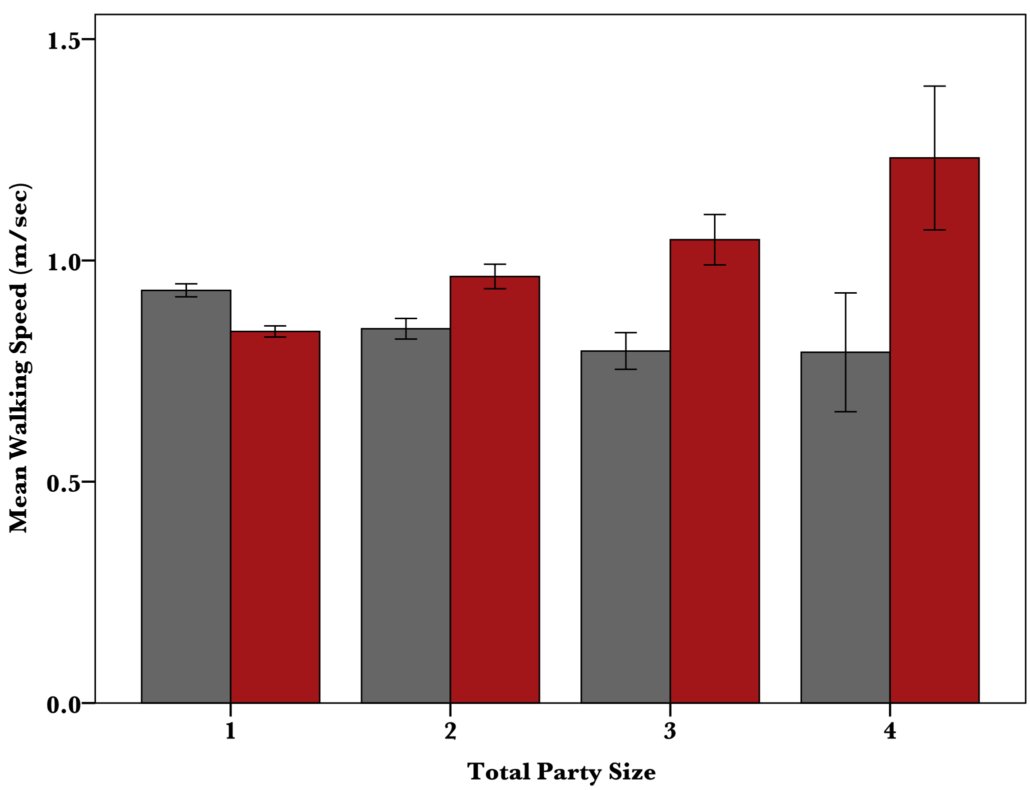

Fig 1: Average speeds of Ugandans (grey) and Americans (red) based on walking group size (x-axis refers to number of people walking in the group). Error bars indicate 95% CI.

Load

In both locations, women were much more likely to be loaded than were men ($p<0.001$). Ugandans walked significantly slower when loaded, while Americans walked significantly faster when loaded ($p<0.001$ for both). Goods (e.g. purses, backpacks, or items for sale) were the most common load type for both locations, constituting 73% (n=1,061/1,449) of loads carried. In both locations, food and goods, but not children, were carried at similar speeds (Fig. 2; $p<0.01$). In Uganda, load position did not significantly impact speed, except that people walked significantly faster when back-loaded than when front-loaded ($p<0.05$). In America, people walked slower when back-loaded (e.g. with a backpack) than when front-loaded ($p<0.001$).

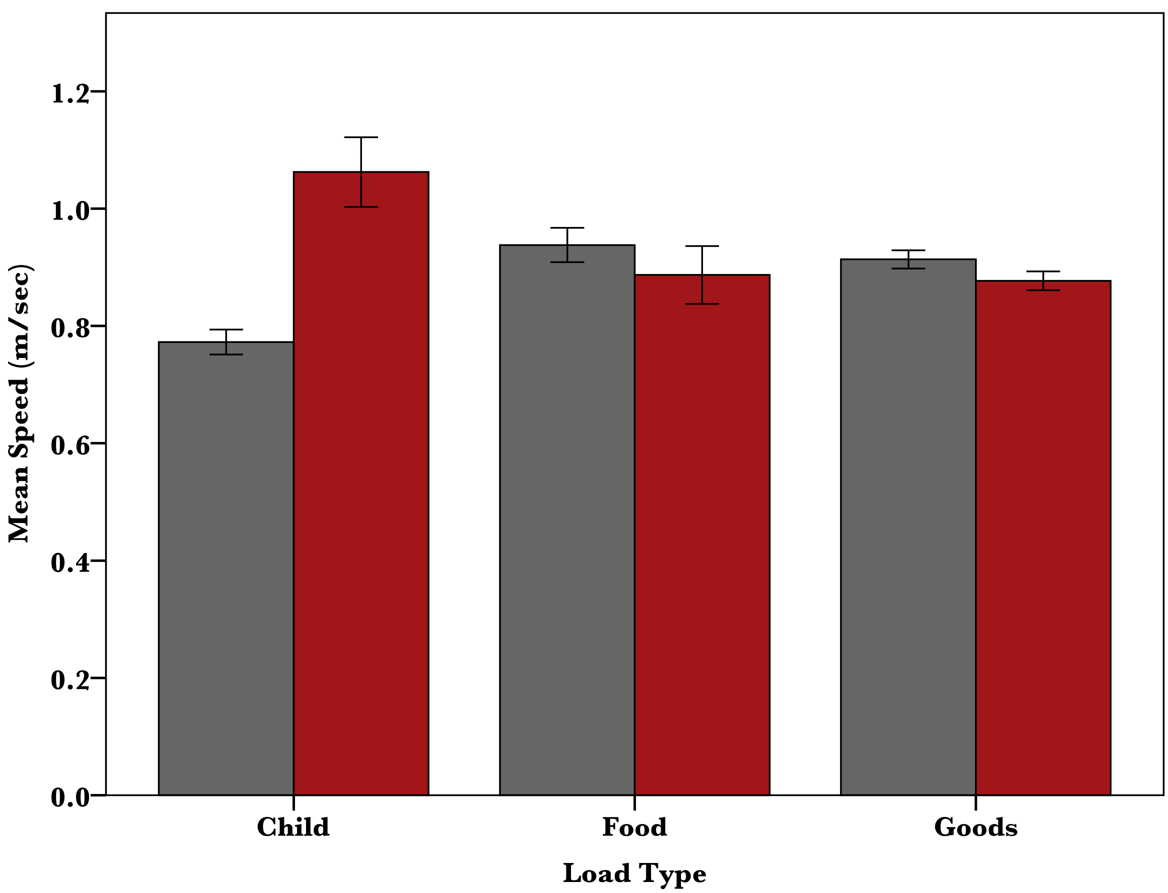

Fig. 2: Average speeds of Ugandans (grey) and Americans (red) carrying either children, food, or goods. Error bars indicate 95% CI.

Children

Of the 1,449 people carrying loads, 158 carried children (11%). The effect of carrying children on speed highly depended on location ($p<0.001$). Ugandans walked significantly more slowly when carrying children than when carrying food or goods (Fig. 2; $p<0.01$), while Americans walked more quickly (Fig. 2; $p<0.01$). These relationships remained significant when child loads were compared to food or good loads of the same size category ($p<0.01$). Americans' speed did not differ significantly amongst food, goods or strollers ($p>0.05$). Women (143/158) were overall more likely to carry children than were men (15/158; $p<0.01$). American children were more often carried on the front (n=11/15) than the side (n=3/15) or back (n=1/15). Ugandan children were most frequently carried on the front (n=57/143) or the side (n=56/143) of the subject. While Ugandan women carried children on their fronts, backs, or sides, Ugandan men never carried children on their backs but only on the front or side. Position of the child load was not significantly correlated to speed in either location ($p>0.05$).

Amongst Ugandans, women carried infants (n=100/133) more often than toddlers (n=31/133) and children (n=2/133), while men carried toddlers (n=7/11) more often than infants (n=4/11). American women and men did not carry infants at a higher rate than toddlers. Age group of the child load had no significant relationship to speed ($p>0.05$).

Whether children were present in the walking group significantly influenced speed ($p<0.001$); however, once children were present (n=304), there were no significant differences between whether children were carried, walked by themselves, or were pushed in a stroller ($p= 0.168$). American groups walked faster when children were present, while Ugandan groups walked slower when children were present ($p<0.001$).

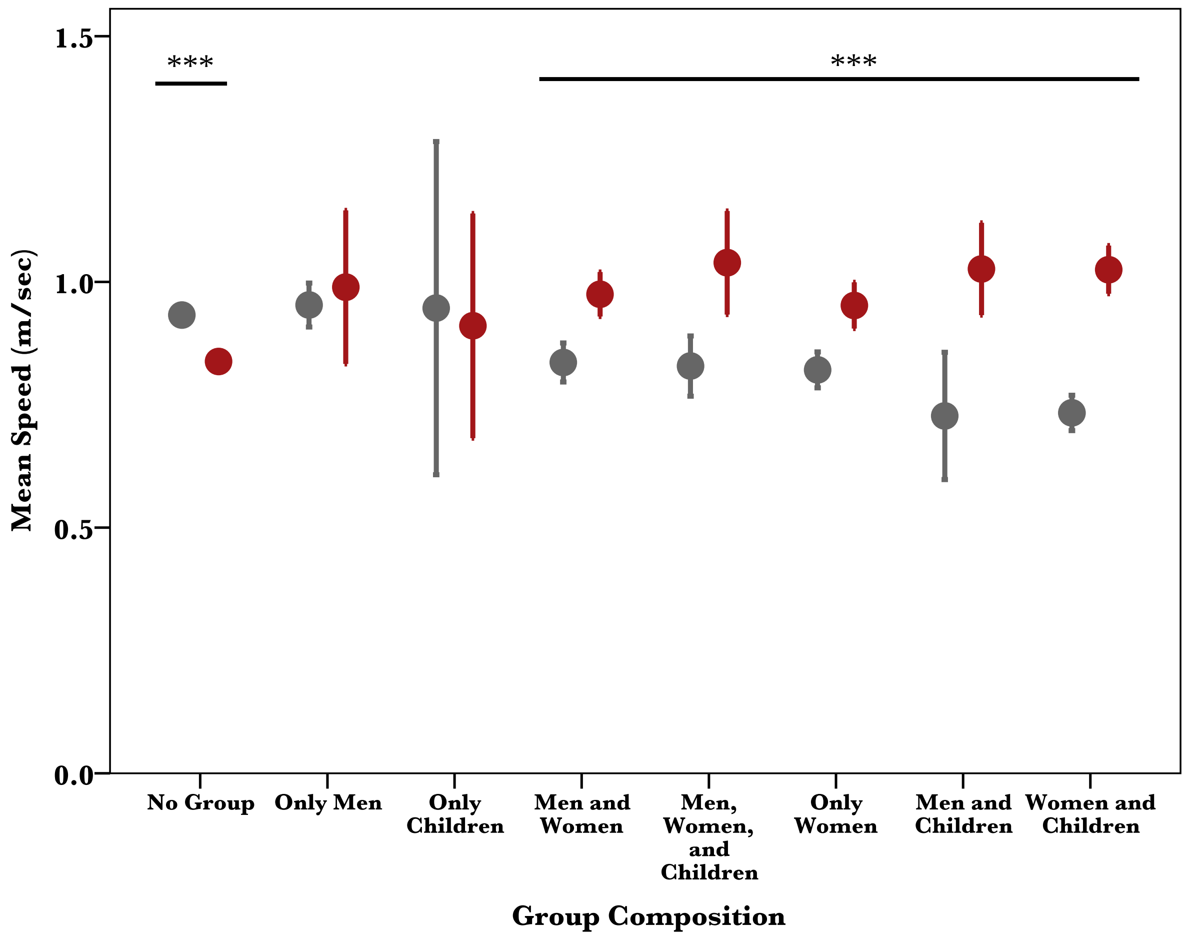

Figure 3: Average speeds of Ugandans (black) and Americans (red) based on walking group composition. Asterisks indicate significant speed differences between populations at $p<0.001$.

Group Composition

The effect of group composition on walking speed is highly dependent on the population location (Fig 3, $p<0.001$). Amongst Ugandans, the walking speeds of men-only groups, groups with men, women and children, and groups of children are not significantly different from the walking speeds of individuals alone ($p=0.939$). All other group compositions (see Fig. 3) walk more slowly than people walking alone ($p<0.05$), but do not show any significant differences from each other (e.g. groups of men with children walk about the same pace as groups of women with children).

Amongst Americans, groups of only children walked at similar speeds to individuals walking alone ($p>0.986$) while all other group types walked faster than individuals walking alone ($p<0.01$). There were no significant differences in speed between any American group types.

Sex Differences in Group Walking

While group composition was significantly correlated to speed in both populations ($p<0.05$), there was a significant interaction between walker sex and their group composition only in the Ugandan population ($p<0.01$). In Central Uganda, men alone walk significantly faster than men walking with other men ($p<0.05$) while men alone in the West Coast United States walked significantly slower than men walking with other men ($p<0.01$). Ugandan women tended to walk more slowly in groups of women than when alone ($p=0.1$), but American women walk faster in groups of women than when alone ($p<0.001$).

			Count		Mean Speed (m/sec)	
			Central Uganda	W.C. United States	Central Uganda	W.C. United States
Load Condition	Unloaded	Male	48	143	1.02	0.84
		Female	16	64	0.90	0.90
	Loaded	Male	307	194	1.00	0.87
		Female	598	350	0.84	0.89
Load Type	Child	Male	11	4	0.81	1.06
		Female	132	11	0.77	1.06
	Food	Male	69	15	1.01	0.85
		Female	90	37	0.88	0.90
	Goods	Male	227	171	1.00	0.87
		Female	376	287	0.86	0.88
	Stroller	Male	0	4		0.99
		Female	0	16		0.95
Subject Party	Alone	Male	258	273	1.03	0.83
		Female	405	278	0.87	0.84
	Group	Male	97	65	0.91	0.96
		Female	209	136	0.80	1.00
Children Present	No Children	Male	329	303	1.01	0.85
		Female	432	351	0.87	0.87
	Children Present	Male	26	35	0.82	0.98
		Female	182	63	0.78	1.01

Table 1: Count and mean speeds of walkers in Central Uganda and West Coast United States. No subjects walked with strollers in the Central Ugandan population.

DISCUSSION

We find that people walking in an urban, errand-running setting in Uganda make different walking speed choices compared to a similar population in the Northwest United States. While American walkers tend to increase their speeds when walking in groups, Ugandan walkers decrease their speeds when walking with others. Ugandans alone walk faster than Americans alone, even though all group types of Ugandans walked slower than their American counterparts. This difference in speed decisions also extended to individuals walking alongside or carrying children; Ugandans slow down when children are present while Americans speed up. In both populations, children were carried at significantly different speeds than similarly-sized loads of food or goods.

Selecting a speed for a particular walking task influences a complex set of interactive variables that include both physiological variables (metabolic energy expended, heat load, and water loss) as well as behavioral (time spent on the tack and the possibility of socialization) (Wagnild and Wall-Scheffler 2013; Wall-Scheffler and Myers 2013, 2017). Because of the habitual nature of walking, small differences in these costs will accumulate into large changes over time. Speed adjustment decisions, then, are expected to be the product of selective tradeoffs for minimizing costs and thermoregulatory burdens, but still maximizing task accomplishments (Miller et al. 2012; Wall-Scheffler and Meyers 2013). In the present study, we observe that Ugandan and American walkers choose different speed strategies in an urban errand-running setting.

Ugandans in groups, for example, accept a higher time cost by selecting slower speeds in groups than alone. This strategy has been widely observed in ecological (Costa 2009) and controlled walking (Frimenko, Goodyear, and Bruening 2016; Wagnild and Wall-Scheffler 2013) studies. Two main reasons have been suggested as to why people choose to slow down when walking together. First, differences in optimum walking speed based on size and sexual dimorphism require faster group members to deviate from their optimum speed to accommodate slower walkers in the group (Costa 2010). Second, slower walking speeds are correlated to closer interpersonal distances between walkers, such that any increased costs from walking more slowly may be outweighed by the benefit of social investment and bonding (Costa, 2010; Wagnild and Wall-Scheffler, 2013; Wellens and Goldberg, 1978). Faster walkers exhibit less alignment with their walking partners, so interpersonal contact may have to be sacrificed to walk quickly. Our data for Ugandan mixed sex groups, groups of women, and groups with children are consistent with these two explanations. Our finding, though, that Ugandan men walk more slowly with other men than when alone challenges an existing framework for men. It has been accepted that Western men speed up when walking with other men due to a high societal emphasis on hierarchy and competition among males (Boles 1981; Costa 2010; Wagnild and Wall-Scheffler, 2013). A difference in male-male relationship dynamics would explain the slower walking speeds, and potentially psychological closeness of Ugandan men.

Gendered relationship norms vary across cultures. These norms prescribe appropriate interactions between genders, including interpersonal distances. Baxter (1970), for instance, finds that interpersonal distances of same- and mixed-sex pairs differed based on ethnicity in the United States. Traditionally gendered traits, such as competitiveness, have also been shown to vary culturally. Amongst the matrilineal Khasi, for example, women show higher competitiveness than men, while men tend toward competitiveness in patrilineal cultures (Gneezy, Leonard, and List, 2009). The Baganda, Central Uganda's predominant ethnic group, are a patrilineal group like most Western cultures (Wyrod, 2008). Contact cultures like the Baganda, though, have been shown to interact at closer distances than people from non-contact cultures like the United States (Remland, Jones, and Brinklan, 1995). Tendency toward closer interpersonal contact may explain why all walking groups, including groups of men, slow down when walking together – because slowing down leads to closer contact between walkers (Costa, 2010).

We also find that, in both Ugandan and United States populations, children are carried at significantly different speeds than other load types. That children are transported differently than other loads is widely recognized (Kramer 1998, 2004). Infant carrying emerged early in the primate lineage, whereas foraging-related burden carrying has been thought to emerge in early members of the genus *Homo* (Rhinegold and Keen 1963; Ross 2000; Leonard and Robinson 1997). We can expect then, that these two types of load-carrying evolved under different constraints.

Our data show that children are carried at faster speeds than other loads in the North American population, but at slower speeds in the Ugandan population. Kramer (1998) predicts that mothers should carry their infants rather than allow them to walk independently when the carrying mother's energy expenditure is less than that of the independently walking pair. At faster speeds, she argues, it is beneficial to carry the child. Our data, though, show that groups with children being carried walk at similar speeds to groups with children walking in both populations. Our finding that Ugandans walk slower when walking with children is consistent with data showing that younger children have a higher minimum cost of transport than older individuals (DeJaeger, Willems, and Heglund 2001). That Ugandans also carry children at slower speeds, though, seems to conflict with Kramer's model. Either Ugandan's choices are influenced by parental care norms not addressed in Kramer's model, or the nature of Ugandans' walking task differs from Americans'. As discussed above, interpersonal contact is more normative in Baganda culture than in Western cultures. Infants in African groups such as the !Kung or Gusii are held or touched about 70-80% of daylight hours, compared to 12-20% in industrialized nations (Hewlett 1996). Higher contact norms unaccounted for in Kramer's model may impact the decision to carry a child, even at slower speeds. It is also possible that Ugandans choose to carry at slower speeds because their errand-running task requires walking longer distances. In this case, it is energetically favorable to incur child-carrying costs because allowing a child to walk over long distances will accumulate into greater total energy expended for the pair and larger time-costs.

The sweeping differences in walking speed in groups and when carrying children between Central Ugandan and Northwest United States populations accentuates the role of culture and environment in mediating energetic decisions. In the future, greater efforts should be taken to understand the ways in which walking behaviors vary across cultures. Our data also show that existing models of locomotor energetics are specific to one population and may not generalize across cultural groups. It is also important to recognize the ways in which behavioral differences between groups, either between sexes or across populations, are influenced by external social factors such as dominance structures in addition to innate biological or morphological differences (Travis and Yeager, 1991). Such recognition builds an understanding that behaviors are environmentally situated processes rather than static attributes.

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FAITH AND LEARNING REFLECTION

Scientific study spans from seemingly obscure and theoretical fields of study to fields directly working to solve human problems. Often, scientists whose work is further removed from societal applications find themselves defending the value of their study, while scientists whose focus is on application find themselves defending the credibility of their science. All scholarly work seeks to build knowledge of the world in a new way. Yet in this process, scholarship can unknowingly distance itself from the concerns of everyday people. A unique integration of high-level knowledge and impactful and direct application drew me to biological and medical science. Understanding human physiology builds a platform to understanding the most effective ways to promote health and flourishing in communities. At each step of my growth as a scientist, I have endeavored to plant a foot both in knowledge and in application. As I finish my studies at Seattle Pacific University, my honors project represents a new extension of this commitment.

My honors project research integrates my interest in culture with my knowledge of biology. Through studying evolution and human physiology in classes at SPU, I grew interested in how evolution shapes physiological differences between people. Throughout my life, I have been fascinated by how cultures uniquely approach the demands of survival. As I traveled internationally, questions arose as to how these differences played out differently in different cultures. In a previous trip to Uganda, I observed young children carrying infants that rivaled them in size and later wondered whether this strategy could be evolutionarily beneficial. Through collaboration with Dr. Wall-Scheffler at SPU, I learned about the importance of locomotor strategies and burden carrying on human morphology and evolution. When the opportunity arose for me to study abroad in Uganda, I knew I finally would be able to apply biology to understand Ugandan culture in a new way.

A scholarship focused on application extends into my longer-term career aspirations. Though the leap between cell culture labs and meeting the needs of my community may seem like a large one, I make it my task to anchor my academic work in application to solving human problems. In writer Ernest Boyer's words, such service "must directly be tied to one's special field of knowledge and relate to, and flow directly out of, this professional activity" (Boyer 22). As a scientist, my scholarship demands reverence for and stewardship of creation from bacteria to ecosystems. As an aspiring physician, I must learn to transform scientific scholarship into a vehicle of hope for those caught in sickness. Boyer also emphasizes the interrelatedness of discovery and application. “New intellectual understandings,” Boyer writes, “can arise out of the very act of application” (23). Through this lens, medicine exemplifies the scholarship of application. Though founded on billions of research dollars and a desire for novel discovery, medical science gains meaning only through application to human lives.