THE AGING MOVER: A PRELIMINARY REPORT ON CONSTRAINTS TO ACTION*

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ABSTRACT
Locomotion by older adults is typically characterized by performance declines. Older individuals walk more slowly, take shorter steps, and spend a longer time in support than young individuals. Investigators assumed implicitly that declines are related to an inevitable aging process. The purpose of this investigation was to examine constraints that might result in the declines described, outside or in addition to, the general process of aging. We examined two types of terrain over which locomotion might occur, level ground and stairs, and two movement speeds, preferred and fast. Healthy, active females between twenty to eighty years were videotaped. Individuals over sixty years walked at significantly slower speeds, particularly climbing stairs. They used a smaller range of speeds than younger individuals. Despite this slowing, the pattern of coordination between limbs remained essentially the same across the ages tested. The small magnitude of declines observed was attributed to the good health and active lifestyles of these individuals.

Locomotion has been studied extensively in older adults. General findings indicate older individuals walk more slowly than younger adults [1, 2]. They are characterized by shorter steps, with higher step cadence, and longer time spent in the support phase than their younger counterparts. Older individuals also produce less force during landing and toe-off phases of walking [3]. Few investigators have gotten beyond these descriptions of changes in patterns used by older adults.

*This work was supported in part by funds to Kathleen Williams from the Summer Research Program at the University of North Carolina at Greensboro.
to examine processes which might underlie the observed changes. Instead, it is implied the gradual process of aging results in the documented declines.

Developmental psychologists have not been satisfied with the use of age as an explanation for change at any point of the lifespan [4]. Perhaps other factors contribute to the declines that often are attributed to the “natural” course of aging [5]. For example, there may be physical changes (poorer eyesight or increased weight) or environmental conditions (dimly lit stairwells or slippery soled shoes) which interact to result in the declines associated with growing older.

These physical changes and environmental conditions are called constraints [6]. Height, weight, and strength are examples of internal or physical constraints that can influence how a movement is performed. Examples of external (environmental) constraints are speed (whether to go all out, at a preferred pace, or slowly) and height (stepping from the top of a porch, or from its bottom step). Kelso and Schön suggested that the interplay between internal and external constraints resulted in the actual “shape” of an action [6]. For example, the height of a stair (an external constraint) that an individual may comfortably climb is limited by the length of the leg (an internal constraint) [7].

The search for constraints responsible for the specific shape of a movement is one part of a “synthetic strategy” [6]. This strategy is intended to lead to understanding biological coordination. It is based on the tenets of the dynamical systems perspective [8-10]. Proponents of dynamical systems see actions as arising spontaneously from the self-organizing properties of the biophysical system, consisting of the actor and environment. Neuromuscular collectives, or coordinative structures [9, 11] are assembled temporarily for the performance of an action within a specific environment context. An actor will shift spontaneously to a different behavioral mode when demands reach a certain, critical point [6, 12]. This new behavioral mode is typically stable over additional small changes in the constraint. These shifts demonstrate that the influence of constraints like speed are non-specific and non-prescriptive [6, 13]. Scaling up to a certain point does not result in switching to a different “motor program” [14], rather, the outcome is a different more stable mode of action.

A systematic investigation of the influence constraints have on motor performances of older adults has not been carried out. The need to examine them has been emphasized by Yates who suggested the process of aging resulted from a “progressive loss of dynamical stability dependent on changing constraints” [15, p. 97]. He further proposed that some human subsystems (like the cardiovascular system) may be more susceptible to changing constraints than others. There is additional evidence that constraints may contribute to the “declines” often cited as a result of aging. Craik suggested that diminished range of motion at the hip and shoulder were related to the slower speeds individuals used, rather than their age [16]. Her conclusions were based on findings that older adults walking at the same speed as younger adults had similar movement characteristics. Gabell and Nayak found similar walking patterns among healthy older and younger adults [17]. In
another investigation, older women freely selected slower speeds than their younger counterparts [18]. These findings suggested that factors other than simply equating for speed are important.

In her review of locomotor changes in older adults, Craik called for the systematic investigation of a wide variety of task- and health-related factors to determine the actual causes for the observed declines [16]. The purpose of this investigation is to begin the systematic study of internal and external constraints on aging. Specifically, speed or pace (an internal constraint), and where locomotion occurred (over level ground or climbing stairs—an external constraint) were examined. Pace was selected because, as reported above, findings related to this variable are equivocal. Two paces were used, preferred, or most comfortable, and fast. Walking over level ground and stair climbing were contrasted as different types of terrain. While stair climbing appears to be a special case of walking, there is a paucity of research regarding this motor skill. This is important, since adults often report formally [19] and informally that they experience increasing difficulty performing this fundamental task as they grow older.

In the context of changing constraints, the following questions were addressed in this preliminary investigation. First, did changes in a constraint, as demonstrated by either movement pace or terrain result in changes in the general "output" of the motor system? Age was also investigated for its contribution to changes in movement speed. Second, would coordination between the limbs be similar for the two types of terrain across different movement speeds? And, would participants’ ages be related to any changes that occurred?

**METHODS**

**Participants**

Adult women, aged twenty to eighty years, were tested in this investigation. They were divided into four groups: 20-29, 50-59, 60-69, and 70-80 years (Table 1). All participants were recruited from the University of North Carolina at Greensboro and Greensboro, N.C. community. Subjects between sixty to eighty years old were required to have a physician’s clearance prior to participation in this study. All participants certified they were healthy and free from any neuromuscular, orthopedic, and cardiac problems which might influence their ability to participate. All individuals read and signed an informed consent form before participating.

**Data Collection**

Testing took place in the Biomechanics Laboratory at the University of North Carolina at Greensboro. Experimental procedures were explained to subjects and their questions were answered. Then, reflective markers were placed over joint
centers of the fifth metatarsophalangeal, ankle, knee, hip, shoulder, elbow, and wrist joints. Each individual’s performance was videotaped in the sagittal plane. A camcorder (Panasonic PV330), operating at 30 Hz, with a 1/1000 s shutter, was placed 13.5 m from the plane of movement. When videotaping was completed, subjects completed a series of questionnaires [20] requesting information related to health status and activity level.

**Movement Tasks**

A set of four steps, with 17.8 cm riser height and 27.9 cm tread depth, was used during the stair climbing portion of testing. These steps lead to a platform 1.83 m long. The stairs and platform were bounded by a handrail on the left hand side.

Participants began each trial approximately 3 m from the bottom of the first step. They were instructed to walk to the stairs, climb to the top, and continue to the back of the platform. The handrail was available for use by those who needed it. Participants were encouraged to climb the stairs without it, if possible. Because all of our participants encountered stairs on a daily basis (see Results), handrail availability was determined to be sufficient as a safety device.

Participants were also encouraged to begin climbing the stairs by placing their right foot first on the bottom step. They were asked not to “adjust” their steps for a right-footed landing in preparation for reaching the first step. Individuals were given several practice trials before videotaping began. Then, at least five trials for each condition were videotaped. Trials were repeated when participants used the

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**Table 1. Subject Characteristics**

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
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<tr>
<td>20</td>
<td>6</td>
<td>27.7</td>
<td>170.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>61.5&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td></td>
<td></td>
<td>(1.8)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>(5.9)</td>
<td>(6.8)</td>
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<tr>
<td>50</td>
<td>5</td>
<td>53.2</td>
<td>166.1</td>
<td>64.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.6)</td>
<td>(6.8)</td>
<td>(12.6)</td>
</tr>
<tr>
<td>60</td>
<td>7</td>
<td>64.0</td>
<td>161.9</td>
<td>63.5</td>
</tr>
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<td></td>
<td></td>
<td>(3.6)</td>
<td>(1.7)</td>
<td>(8.7)</td>
</tr>
<tr>
<td>70</td>
<td>6</td>
<td>73.3</td>
<td>160.8</td>
<td>61.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3.9)</td>
<td>(4.4)</td>
<td>(12.2)</td>
</tr>
</tbody>
</table>

<sup>a</sup>Centimeters
<sup>b</sup>Kilograms
<sup>c</sup>Standard deviations are in parentheses.
left foot on the first step or made an obvious preparatory adjustment. Despite these precautions, data for at least one trial were lost for seven individuals (individuals made obvious adjustments in preparation to contact the first stair that went undetected during filming). As a result, data for four trials for each condition were available for each participant.

Data Analysis

Videotapes were analyzed using a Peak Performance Analysis System (Peak Performance Technologies, Inc., Boulder, CO). Each frame is "split" using this system, resulting in an available sixty fields/s for data analysis. Horizontal and vertical coordinates of the hip were digitized electronically and stored for additional processing. These points were smoothed at 6 Hz using a low pass, fourth order, zero lag Butterworth digital filter. Horizontal, vertical and resultant velocities were derived from the smoothed data. Additionally, the single frame advance capabilities of the system were used to determine when significant events occurred, such as touchdown and toe-off.

Walking and climbing velocity — Resultant velocity was the primary measure of movement speed used, because both horizontal and vertical velocity were important as participants climbed stairs. Age differences in horizontal and vertical components of movement velocity during stair climbing were also analyzed.

Each individual’s right hip was digitized, beginning with the frame that was a minimum of three steps before her initial contact with the bottom stair. Two complete steps were digitized to determine her walking pace. The step just before landing on the stair was not used to avoid including the braking phase which occurred in preparation for arriving at the first stair. Stair climbing velocity was based on individual’s speed climbing the middle two steps. Digitizing began at toe-off of the second foot (generally the left) from the floor. It continued to touchdown by the first foot (generally the right) reaching the third step. For both walking and climbing, velocity was determined as an average across the frames digitized.

Interlimb coordination — Relative temporal phasing between the lower limbs was examined as an indicator of interlimb coordination. Relative phasing refers to the relationship between the limbs during the locomotor cycle. For infants and young adults, one leg is 50 percent out-of-phase with the other [21]. That is, floor contact by one foot is made halfway through a complete cycle made by the other foot. Temporal phasing between the lower limbs and its variability were investigated to determine whether task or movement pace constrained performers of increasing age differently. Temporal phasing was the average phasing determined for each participant; variability was defined as each participant’s standard deviation about her own mean.
RESULTS

Health and Activity Level

All participants reported that their health was either good (55.6%) or excellent (44.4%). No age differences were apparent in the level of health reported by the women in this investigation. While several individuals reported the presence of ailments (e.g., arthritis, heart disease), none felt that it impeded their ability to perform any locomotor activity. Specifically, three individuals reported having controlled hypertension, and two had had heart attacks (before 1975). Interestingly, these two individuals were among the most active of our participants. Some participants reported having arthritis, but none had symptoms in the lower back or limbs.

Although 78 percent of our participants reported they were not currently involved in vigorous activity (running, swimming, etc.), 83 percent said they were active regularly in less vigorous activities (e.g., walking, gardening). There were no age differences in the frequency of involvement. Several participants in each age group were involved in activity four or more times per week; one or two in each group were active once or twice weekly.

All participants climbed stairs as part of their regular daily activities. Most had stairs in their homes; all encountered them in their daily environments. Only one individual (an 80-year-old) reported avoiding stairs if an elevator was available. Although she stated this preference, she too used stairs on a daily basis (at the entry of her home and on her way to an activity program in which she participated three times per week).

Walking and Climbing Velocity

An initial age (4) x terrain (2) repeated measures analysis of variance was performed to determine if participants of different ages used different movement speeds for the two tasks. All remaining analyses of walking and climbing velocity were performed separately.

For the initial analysis, there were significant age and terrain main effects: age: $F_{3,20} = 7.35, p = .002$; terrain: $F_{1,20} = 137.96, p < .001$. There also was a significant age x terrain interaction: $F_{3,20} = 3.35, p = .04$. Post hoc Scheffe analysis of differences within the interaction demonstrated there were greater distinctions between the speeds used by the twenty- and fifty-year-olds than there were for the sixty- or seventy-year-olds (Figure 1). Twenty and fifty-year-olds moved more slowly when climbing stairs than when walking over level ground. In contrast, there was little difference between speeds used by older individuals. These latter two groups moved more slowly than younger individuals, regardless of terrain (Figure 1).

Although participants were encouraged to rest as often as necessary, we wanted to see if fatigue could be a factor in their speed of movement. In order to determine
whether fatigue might have occurred, age (4) × pace (2) × trials (4) analyses of variance, with repeated measures on the last two factors, were performed on the walking and climbing data.

For the walking data, there were significant main effects for age and pace: age: $F_{3,16} = 8.48$, $p = .001$; pace: $F_{1,16} = 161.63$, $p < .001$. There also was a significant age × pace interaction: $F_{3,16} = 6.46$, $p = .005$. The main effect for trials was nonsignificant ($p > .05$). For the climbing data, there were significant main effects for age and pace and a significant interaction for age and pace: age: $F_{3,16} = 4.41$, $p = .02$; pace: $F_{1,16} = 64.75$, $p < .001$; age × pace: $F_{3,16} = 4.06$, $p = .03$. There was also a significant main effect for trials on the climbing data: $F_{3,48} = 3.42$, $p = .02$. A follow-up Scheffé analysis revealed no simple differences between trials. Because there was no clear pattern of trial differences, data were collapsed across trials for the remaining analyses.

Separate simple effects analyses of variance, with paces (2) nested in ages (4) were performed on the walking and climbing data. Simple effects analyses were used to examine the ages at which participants could use two distinctly different movement paces. For walking, there were significant pace differences for the twenty-, sixty-, and seventy-year-olds: twenty-year-olds: $F_{1,20} = 40.92$, $p < .001$; sixty-year-olds: $F_{1,20} = 10.00$, $p = .004$; seventy-year-olds: $F_{1,20} = 8.26$, $p = .009$. For those three age groups, participants walked faster at their "fast" pace, than at their
There were no significant differences in the speeds used by the fifty-year-olds ($p > .05$) for the two walking conditions. For stair climbing, twenty-, fifty-, and sixty-year-olds climbed stairs faster in the fast condition; compared with their preferred pace: twenty-year-olds: $F_{1,20} = 32.49, p < .001$; fifty-year-olds: $F_{1,20} = 14.88, p = .001$; sixty-year-olds: $F_{1,20} = 6.70, p = .02$. There were no differences in the speeds used by the seventy-year-olds ($p > .05$) for the two climbing conditions (Table 2).

In the analyses reported to this point, resultant velocities were used for all comparisons. It is possible that participants might have different horizontal and vertical velocity components, yet similar resultant velocities. It was especially important to examine this possibility for stair climbing, where participants were working against gravity. It was of interest, therefore, to determine if change in one velocity component more than the other contributed to the pattern of age-related differences reported. That is, did older adults climb stairs more slowly as a result of a relatively slower vertical or horizontal velocity component?

The horizontal and vertical velocity components of the climbing data were analyzed across age and pace conditions. A simple effects analysis of variance, Table 2. Age Differences In Resultant Velocities for Walking over Level Ground and Stair Climbing at Two Speeds

<table>
<thead>
<tr>
<th>Age</th>
<th>Preferred</th>
<th>Fast</th>
<th>Preferred</th>
<th>Fast</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-year-olds</td>
<td>1.55(c)</td>
<td>2.08</td>
<td>0.86</td>
<td>1.39</td>
</tr>
<tr>
<td></td>
<td>(0.24)(d)</td>
<td>(0.21)</td>
<td>(0.41)</td>
<td>(0.41)</td>
</tr>
<tr>
<td>50-year-olds</td>
<td>1.61</td>
<td>1.75</td>
<td>0.91</td>
<td>1.30</td>
</tr>
<tr>
<td></td>
<td>(0.10)</td>
<td>(0.42)</td>
<td>(0.15)</td>
<td>(0.26)</td>
</tr>
<tr>
<td>60-year-olds</td>
<td>1.48</td>
<td>1.73</td>
<td>0.81</td>
<td>1.03</td>
</tr>
<tr>
<td></td>
<td>(0.18)</td>
<td>(0.12)</td>
<td>(0.13)</td>
<td>(0.15)</td>
</tr>
<tr>
<td>70-year-olds</td>
<td>1.25</td>
<td>1.49</td>
<td>0.72</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td>(0.10)</td>
<td>(0.08)</td>
<td>(0.10)</td>
<td>(0.05)</td>
</tr>
</tbody>
</table>

\(~p<.01\) for 20-, 60-, and 70-year-olds.
\(p<.001\) for 20- and 5-year-olds; \(p<.05\) for the 60-year-olds.
\(m/s\)
\(Standard deviations are in parentheses.\)
with age and pace nested in velocity component (horizontal and vertical) was performed on the climbing data. There were significant pace changes across ages in the horizontal component \((p = .014)\). The pattern of age differences for this horizontal velocity component was similar to that described for resultant velocities. That is, the difference in climbing speed for the two pace conditions was greater for the twenty-year-olds than for the sixty- or seventy-year-olds. Climbing speed differences were also larger for the fifty-year-olds than the seventy-year-olds. No age-related change in movement velocity occurred for the vertical component \((p > .05)\).

**Interlimb Coordination**

Temporal coordination between the limbs was investigated using each individual's mean relative phasing and variability. Mean phasing was the average temporal phasing across trials for each condition, for each individual. Variability was the standard deviation about the mean phasing for any condition. Separate age \((4) \times \) terrain \((2) \times \) pace \((2)\) analyses of variance, with repeated measures on the final two factors, were performed on the relative phasing and variability data.

No significant differences occurred for any effect or interaction for relative phasing \((ps > .01)\). Regardless of age, terrain, or movement pace the lower limbs remained in the 50 percent out-of-phase relationship (Figure 2).

There were significant age, terrain and pace differences for the variability measure: age: \(F_{3,20} = 4.54, p = .01\); terrain: \(F_{1,20} = 12.58, p = .002\); pace: \(F_{1,20} = 7.00, p = .01\). Additionally, there were significant age \(\times\) pace and terrain \(\times\) pace interactions: age \(\times\) pace: \(F_{3,20} = 4.25, p = .01\); terrain \(\times\) pace: \(F_{1,20} = 8.04, p = .01\). No other interactions were significant. A follow-up, simple effects analysis of variance, with ages \((4)\) and terrains \((2)\) nested in paces \((2)\) was performed to determine the nature of the differences within the interactions. There were no significant age or terrain differences when participants moved at their preferred pace \((p > .05)\). There were, however, significant differences when individuals traveled at their fastest pace: age: \(F_{3,20} = 6.52, p = .003\); terrain: \(F_{1,20} = 14.75, p = .001\). The youngest participants were less variable than any of the older participants (Figure 3). None of the older age groups differed from one another. In addition, when moving their fastest, performers of all ages were more variable in their phasing while climbing stairs than when walking over level ground (Figure 3). For all conditions, variability ranged between 1-3 percent, within system measurement error. While statistically significant, the question of practical significance must be addressed.

**DISCUSSION**

The purpose of this investigation was to examine the influence of two constraints, movement pace and terrain, on participants' actual movement velocity...
and interlimb coordination. We wanted to know whether older individuals could produce different movement velocities under differing constraints. In addition, we wanted to know how these constraints might influence coordination between the limbs that underlies the observed movement velocities.

Our data suggested that the constraints, terrain, and pace, had differential effects on movement velocity across the ages tested. While older individuals generally moved more slowly than younger individuals regardless of task requirements, they also seemed to have a smaller range of speeds available to them. There was little distinction between the speeds they used under the different pacing conditions, especially after sixty years of age. This lack of distinction was especially clear when our oldest participants climbed stairs.
Figure 3. Age and pace (top) and terrain and pace (bottom) differences in variability of relative phasing between the lower limbs.
The differences between the age groups tested in this investigation were significant, but often smaller than expected. While the older individuals (particularly over 60) moved more slowly than their younger counterparts, the essential pattern of interlimb coordination remained the same. Stair climbing posed additional challenges to the oldest participants tested, resulting in slower movement speeds than when walking over level ground. We expected that older participants would have greater difficulty moving against gravity as they climbed the stairs. The generally good health and high level of activity enjoyed by these participants may have contributed to our failure to find differences between walking and climbing conditions. There may be a general slowing in the output of the motor system with age that would heavily influence forward progression. Simultaneously, as long as good health and an active lifestyle were maintained, moving against gravity in a task like stair climbing might not pose any greater challenge to older adults than it poses to healthy, younger individuals.

While studies of older adults often report dramatic declines in many domains after age sixty, the “declines” observed among the participants in this experiment were small. Because of their good health and high level of activity, these participants may have differed from the general population of older adults. Participants were selected for their lack of physical difficulties. Other investigators found that many older adults have one or many health problems. For example, Davies [22] suggested that 20 percent of the population over eighty-five years old may have some sort of pathology. Gabell and Nayak [17] found a high incidence of problems in older adults in their study of walking. They screened 1,187 adults (65 and older), and found only 32 (2.7%) that were free of musculoskeletal, neurological, cardiovascular, or other problems. These data indicate that our participants may have been representative of a special subset of older adults. Future research should compare less fit groups of older individuals to determine if clearer declines occur in any of the measures examined.

These data also suggest that age-related declines in interlimb coordination do not occur. While there was some slowing of movement speed, the essential coordination of locomotor actions remained the same. In fact, it would seem that the “coordinative structure” [9] governing locomotion is present even in very young infants [21, 23] and does not change throughout the lifespan in relatively healthy individuals.

This investigation directly examined only two examples of constraints, movement pace and terrain. By eliminating less healthy or less fit subjects, we also may have investigated the effect of an additional constraint, a global measure of health or fitness. Future investigations need to manipulate level of health or the presence of limiting conditions (like cardiovascular disease, arthritis) for their effect on the performance of these tasks. Additionally, other task-related variables should be examined (e.g., stair height, number of stairs, background/foreground contrast, etc.) for their influence on different groups of older
adults. We may have minimized the differences that we could observe by selecting participants that were above average in health.

There were small age-related differences in the way participants moved, particularly when it came to climbing stairs. What might have caused the differences that were observed? Changes that occur in balance and postural control (see Woollacott [5], for a review) seem the most likely candidates. Previous research suggests that balance is more tenuous among older adults, with the most dramatic declines after age sixty. The stair climbing task forced subjects to balance on a relatively smaller support surface (the step), as they moved away from the floor and against gravity. Standing on one foot while raising the other to the next step presented movers with a more challenging balance situation than walking over level ground. In fact, some of our older participants appeared to try to counteract this balance perturbation by using the handrail. While none of our participants used it for support, several ran their hand along the railing as if to increase their stability. Future research should examine change in balance more directly, for its influence on specific motor tasks like walking over level ground and stair climbing.

In conclusion, consistent age-related differences were found for the speed that individuals used in walking and stair climbing. These data suggest there may be a general, possibly inevitable slowing of the maximum output of the motor system with increased age. However, other variables showed less difference across the ages tested. Specifically, interlimb coordination remained the same, while the variability of that phasing increased slightly. The small increase in variability, and the question of its significance may have resulted from the specific group of individuals tested in this investigation. That is, larger increases in variability may occur only in less fit or less healthy older adults. While this investigation provided an initial look at some additional characteristics of locomotion in older adults, it raised many questions. These questions can be answered only through the careful manipulation of additional internal and external constraints to action.

ACKNOWLEDGMENT

We thank Jill Whitall and Jackie Hudson for their comments on earlier drafts of this paper.

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