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# Abstract

Few studies have been conducted to analyze infant stair climbing, which is a key task in developing motor ability and functional capacity within today's urban environment. This study observed the climbing strategies of one, inexperienced 35 month old child. In order to facilitate behavioral changes and transitions, a single stair apparatus capable of fine dimensional manipulations was utilized in a series of ten trials, five addressing changes in riser height and five for changes in tread depth. Pitch angle, relative riser height, and relative tread depth were calculated and plotted against a coded scale of bipedal climbing behaviors. The study found that the ascent phase for both types of trials resulted in the most behavioral changes, occurring within a range of stability outlined by points of unstability, critical points. His rate limiters for the riser height condition were $24.1^0$ pitch, .26 pi-number and $35.5^0$ pitch, .42 pi-number. His boundaries in the tread depth trials were $35.5^0$ pitch, .59 pi-number and $54.1^0$ pitch,.30 pi-number. Descent for both conditions was absent of varying changes in behavior, which indicates the presence of other rate limiters. Further study is required before generalization this subject's boundaries and quantitative limiters to infant populations.

# Introduction

## Stair Climbing and Affordances

An affordance represents the functional utility of an environmental object in regard to the action capabilities of the individual (Gibson, 1979). Both the individual's capabilities and the object's material characteristics afford whether or not an action can be performed and exist regardless of their perceivance by the actor (Warren, 1984; Mark, 1987). Many studies have been conducted to determine what affordances contribute to the stair climbing, organism-environmental fit (Warren, 1984; Mark, 1987; Ulrich, Thelen, and Niles, 1990; Meeuwsen, 1991; Konczak, Meeuwsen, and Cress, 1992). Variance in the organism-environmental fit produces transitional phases in the actor's behavior (critical points) leading to stable, energy efficient points known as optimal points. There is a perception-action coupling, and in order for an actor to determine if locomotion or any action can be taken, the actor relates the physical aspects of the environment to the self, implying that an intrinsic, body-scaled measuring system is being used. However, anthropometrics are not the only measuring system. Kinematic and kinetic properties of both dynamic systems are also part of affordances. Specifically to stair climbing, hip flexibility and relative leg strength contribute to the affordance of climbing, particularly in different populations, females, males, elderly, etc. (Meeuwsen, 1991; Konczak *et al*, 1992).

As mentioned above, optimal points are energy, metabolic efficient points and in stair climbing are determined by the fit between the climber and the dimensions of the stairway. For example, Warren (1984) found that individuals regardless of height expressed a set of stairs as "climbable" if the riser height of the stairs was equal to or less than 88% of their leg length, and further more chose which set they preferred to climb based on minimum energy expenditure. Mark's 1987 study focused on the role eyeheight-scaled information had on affordances. However, physical capabilities and perceptions change as a function of age (Collins, 1976), and age-limiting factors such as lost of flexibility and strength greatly influences the perceptual judgment of the elderly populations (Konczak *et al*, 1992). Other stair dimensions, such as tread depth and pitch angle, are hypothesized to afford climbability. Maraj, Pickett, and Normand (1999) found distinct conditions for pitch angle while keeping maximum riser height constant. Maraj *et al* suggested that "a range of pitch angles, outside of which stairs' dimensions are no longer perceived as being climbable, may facilitate perception of maximum climbability" (pg. 2). Since tread depth is inversely related to pitch angle, tread depth may also facilitate the climbability of stairs.

Younger populations such as infants and children also display capabilities in perceiving affordances when climbing stairs (Ulrich *et al*, 1990). Ulrich *et al*, through their observations, studied the perceived affordances of infants attempting to climb three sets of stairs of different riser heights. They hypothesized that if the children could indeed perceive the affordances, that is determine the climbability of the stairs based on their sensory interpretation of each set of stairs, then their initial actions would lead to obtaining the desired goal (*i.e.* use the stairs as a pathway to reach the set of toys). Their choices and successes would not be by chance. In their study all modes of climbing and locomotion were considered, including quadruped climbing. Variability within the modes according to affordances of the environment was not investigated.

General Biomechanical Explanation of Bipedal Stair Climbing

Progression from one step to another involves coordinated lifting and horizontal translations. The progression is phasic in nature consisting of both ascent and descent stance and swing phases. Ascent can be categorized into the following stance and stride phases by weight acceptance, pull-up, and forward continuance for stance and, for swing, foot clearance which includes simultaneous lifting of the swing leg and leg positioning for foot placement (McFadyen and Winter, 1988). Muscle groups involved in ascent, thus providing the concentric contractions needed to pull and push the body, are comprised of the quadriceps (rectus femoris), the hamstrings (vastus lateralis), and the calf muscles (soleus and medial gastrocnemius). Descent stance phase can be divided into weight acceptance, forward continuance, and controlled lowering. Swing phase for descent is described similarly to ascent swing phase with leg pull-through and foot placement. Descent requires eccentric, negative contractions since the action is really more about controlling gravity instead of overcoming it (McFadyen and Winter, 1988). Adult climbing follows this description and has been termed alternate stepping, the leg in the swing phase moves to the above step, not the step of the weight bearing leg. However, young children such as toddlers and new bipedal climbers have been observed using a different mode of bipedal climbing, mark-in-time. Unfortunately, a precise biomechanical review of mark-in-time is not currently available, but it does require a lot of the same elements of alternate stepping with one obvious difference, the swing leg does not move to the alternate step but instead is placed on the same step as the weight bearing leg.

Purpose

The purpose of this study is to expand on Ulrich *et al*'s work (1990) and investigate the specific optimal and critical points of child bipedal climbing, through the manipulation of stair dimensions, riser height and tread depth. The study particularly examined the critical points and optimal points that afford the two different bipedal climbing behaviors. It is this experiment's hypothesis that, through changing stair dimensions, transitions in infant stair climbing strategies could be facilitated.

# Method

Subjects

Subject was 35 month old, male with no visual or motor deficits, with moderate experience in level walking, and with minimal or no experience in stair climbing.

Equipment

A two-step stair apparatus capable of changing its tread depth and riser height was designed and utilized for this study. Through the use of a hydraulic motor the bottom step could achieve vertical displacement, effecting the riser height of the initial step. The top step could change both vertically and horizontally, affecting the tread depth of the first step and the riser height of the second. Manipulation of these steps resulted in bi-directional displacement, which affected pitch angle, tread depth, and riser height. Essentially, the apparatus served as several cases of stairs in one machine. Maximum dimensions of the apparatus were 20cm by 28cm, and minimum dimensions were 11cm by 11cm. A video camera was positioned perpendicular to the stairs in order to record movement in the sagittal plane.

Procedure

Upon arrival to the test room the subject was given the opportunity to interact with the experimenters. The experimenters then obtained information on walking and stair climbing experiences from the parents. Next, standing and sitting height measurements were taken. This initial part of the study took 15 min, 10 min to allow for the questioning and adjustment of the subject and parents to the experimenters and 5 min to take the measurements. After the15 minutes, the subject was led to the stair apparatus by the parents. Five trials of horizontal displacement, tread depth manipulation, were conducted, followed by 5 trials of vertical displacement, riser height manipulation. The subject was distracted by the parent or experimenter

with play after each trial to allow the apparatus to change its dimensions, no more than 1 min. Each trial began when the experimenter instructed the parent to "Let him go," and ended when the subject's feet touched the top step or after 1 min had elapsed.

Stair Apparatus Trials

Vertical Displacement Trials (5):
I) 11.0r x 28t cm, $19.7^0$ pitch angle
II) 12.5r x 28t cm, $24.1^0$ pitch angle
III) 15.0r x 28t cm, $28.2^0$ pitch angle
IV) 17.5r x 28t cm, $32.0^0$ pitch angle
V) 20.0r x 28t cm, $35.5^0$ pitch angle

Horizontal Displacement Trials (5):
I) 20r x 28.0t cm, $35.5^0$ pitch angle
II) 20r x 23.5t cm, $40.4^0$ pitch angle
III) 20r x 19.0t cm, $46.5^0$ pitch angle
IV) 20r x 14.5t cm, $54.1^0$ pitch angle
V) 20r x 11.0t cm, $63.4^0$ pitch angle

Experience of Walking and Stair Climbing

Parents were asked to recall when their children could walk with support and then alone (*i.e.* walk a distance of 8 to 10 feet without assistance). Parents were also asked if their child was readily exposed to stairs and how often had they attempted to climb stairs. Based on the frequencies of exposure or the attempts to climb stairs, the subject was classified as having no past exposure or attempt to climb stairs, limited exposures and attempts (<5), or various exposures and attempts (>5).

Qualitative treatment of the data

Coding of the variables seen on the Videotape

1) mark-in-time with use of handrail
2) mark-in-time with hands used for balance
3) mark-in-time
4) alternate stepping with use of handrail
5) alternate stepping with hands used for balance
6) alternate stepping

Based on the sitting height and standing height, leg length for the subject was calculated. Then $Pi_{\mathrm{I}}$ was calculated by Warren's formula: Riser Height/Leg Length (1984). Another pi-number ($Pi_{\mathrm{II}}$) was calculated based on tread depth (Tread Depth/Leg Length), which is related to Warren's second pi-number based on pitch angle and leg length (1984).

Each trail was reviewed and assigned one of the above codes. Then using a graphing program, charts were drawn to demonstrate the changes in behavior at each trail for each pitch angle and pi-number, $Pi_{\mathrm{I}}$ or $Pi_{\mathrm{II}}$.

# Results and Discussion

Even though the study was conduct with only a population of one (N=1), several important observations could be made concerning the subject's perceptions and choices. First, ascent for both trials produced greater behavioral changes then descent, and secondly tread depth manipulation facilitated more change then riser height manipulation.

## Subject Information

The subject interview determined that exposure to stairs and attempts to climb stairs had been limited (<5 times). Sitting height ($H_{sit}$) was measured at 50.0cm, and standing height ($H_{sta}$) was at 97.5cm. Leg length (LD) was calculated to be 47.5cm.

$$H_{sta} - H_{sit} = LD$$

## Riser Height Manipulation Trials

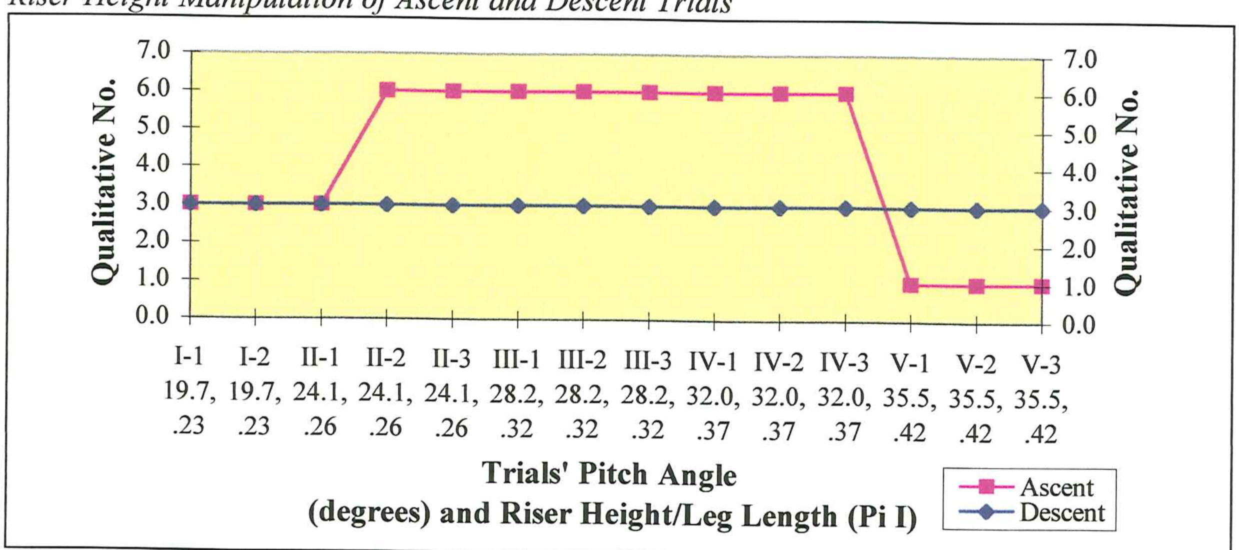
For each trial in ascent and descent, a qualitative number was assigned and a pi-number ($Pi_I$) was calculated based on riser height (RH) and leg length (LD), (Warren, 1984).

$$Pi_I = RH/LD$$

Using a charting program, each trial, pi-number, and pitch angle were graphed with the seen qualitative number for that trial.

Chart 1

*Riser Height Manipulation of Ascent and Descent Trials*




*Note.* Qualitative No. Legend:1-Mark w/ handrail, 2-Mark w/ hands used for balance, 3-Mark, 4-Alter w/ handrail, 5-Alter w/ hands used for balance, 6-Alter

Ascent trials demonstrated several behavioral changes. The first trial with 2 runs showed the same mark-in-time behavior. The subject continued with this behavior for the first run of the second trial (II-1), but then changed to alternate stepping, normal adult behavior. The intra-trial change occurred at a $24.1^0$ pitch angle and .26 pi-number. The subject continued to display alternate stepping throughout the second, third, and fourth trials. The behavior changes again when the subject first attempts the fifth trial runs (V-I to V-3). The subject is no longer at the normal alternate stepping pattern, but has regressed to a mark-in-time pattern, utilizing the handrail for added stability. This inter-trial change occurred at $35.5^0$ pitch and .42 pi-number. It can be concluded that for this subject these two conditions ($24.1^0$ pitch, .26 pi-number and $35.5^0$ pitch, .42 pi-number) are the rate limiters for his ascent system, perception action coupling ability. (See Appendix I for comments on variability within the subject's ascent system for riser height manipulation.). All descent trials demonstrated the same pattern despite the changing riser height. At no time were we able to induce a transition from unassisted mark-in-time. The subject chose a very stable yet low achievement behavior.

<u>Tread Depth Manipulation Trials</u>

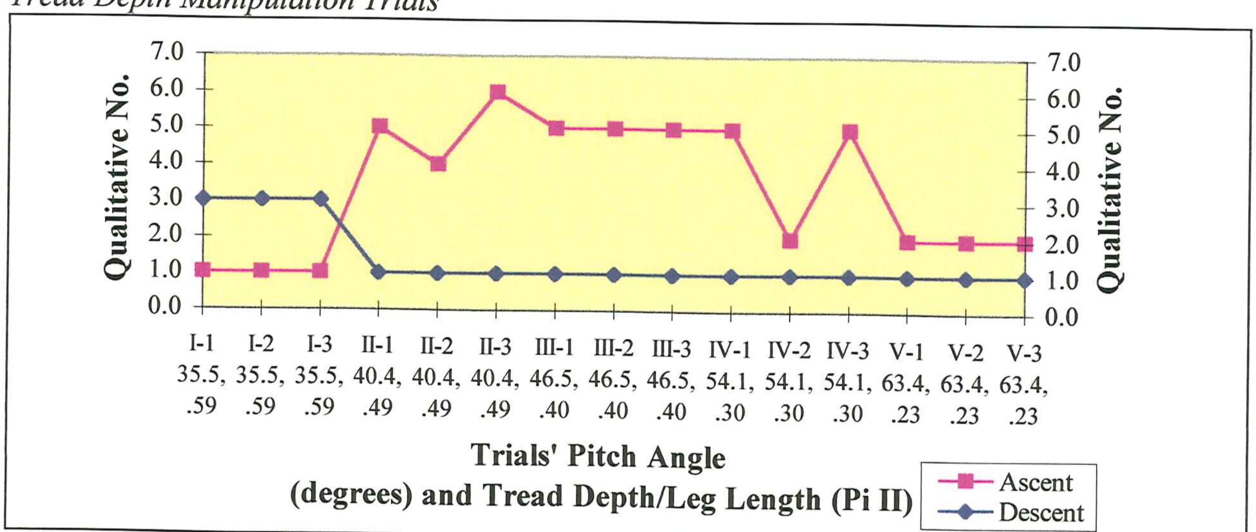
Again, a qualitative number was assigned and a pi-number ($Pi_{II}$) was calculated for each trial in ascent and descent. This pi-number differed from $Pi_I$ since tread depth (TD) was used.

$$Pi\ I_I = TD/LD$$

Using a charting program, each trial, pi-number, and pitch angle were graphed with the seen qualitative number for that trial.

Chart 2

*Tread Depth Manipulation Trials*




*Note.* Qualitative No. Legend:1-Mark w/ handrail, 2-Mark w/ hands used for balance, 3-Mark, 4-Alter w/ handrail, 5-Alter w/ hands used for balance, 6-Alter

Once again, the ascent trials produced the most change in climbing behavior. Inter-trial changes are seen at the first run of the second (I-3 to II-1), third (II-3 to III-1), and fifth trials (IV-3 to V-1). For the first trial the subject continued with his previously established pattern seen in the last riser manipulation trial (V-1 to V-3). Both of these trials share the same pitch angle, tread depth, and riser height. With the first true change in tread depth at $40.0^0$ pitch and .49 pi-number (I-3 to II-1), the subject changes to alternate stepping, outstretching his hands in front of him for added stability. This run did result in a successful climb, but the subject changed his alternate stepping pattern for the next run by using the handrail for even more assistance. Within the same trial (II), the subject again showed an intra-trial change and progressed to alternate stepping without any assistance. As stated above, attempting the first run of the third trial resulted in a change from no assistance to using hands for balance. This self-assisted behavior continued into the for the fourth trial ($54.1^0$ pitch and .30 pi-number) despite the change in relative and absolute tread depth. After this first run, the subject did make an intra-trial change losing the alternate stepping pattern completely for a mark-in-time pattern with the use of his hands for stability. This behavior only lasted for the second run of this trial (IV), since there was a return to alternate stepping with hands in the next and last run of the forth trial. It is noteworthy that intra-trial changes occurred at trials two and four, $35.5^0$ pitch/.59 pi-number and $54.1^0$ pitch/.30 pi-number respectively. Suggesting that these conditions may be the subject's rate limiters. An inter-trial change occurred for the last trial (V) when the subject regressed to the mark-in-time pattern which utilized his hands for balance. Like ascent, the first trial of descent tread manipulation reproduced the same pattern as the last trial of the riser descent manipulations. It was not until a true tread depth manipulation was produced at $35.5^0$ pitch, .59 pi-number did the subject's behavior change. Once the behavioral change occurred, the subject did not alter his pattern, which was the most assisted pattern possible, mark-in-time with use of the handrail.

## Conclusion

Both Ulrich *et al* (1990) and the work done by Warren (1984) provided an excellent starting point to view perceptual action coupling sequences of infant stair climbing. This study on a small scale expanded on stair dimension manipulations by changing riser height and tread depth, which are the components of the pitch angle, and limited the possible pathways the subject chose

by using one set of stairs for the changing dimensions. If the subject was to complete the task at hand, namely climb the stairs, he had to change his climbing behavior instead of choosing another set.

As seen in the ascent trials for both dimensional manipulations, variability in behavior was present suggesting instability, but the subject's behavioral achievement was at a higher level. The two points that marked this sequence of low to high to low achievement for both conditions are the subject's boundaries. Specifically his rate limiters for the riser height condition were $24.1^0$ pitch, .26 pi-number and $35.5^0$ pitch, .42 pi-number. His boundaries in the tread depth trials were $35.5^0$ pitch, .59 pi-number and $54.1^0$ pitch,.30 pi-number. Descent trials were at a very stable, low achievement level, never truly varying in behavior. (See Appendixes II and IV)

Further study is needed to determine the relevance of this subject's behavior to the infant population, to further define the systems critical points and optimal points, and to investigate what other limiters effect infant developing systems, particularly psychological (safety and protection), neurological (balance and vestibular system), and muscular (concentric and eccentric development).

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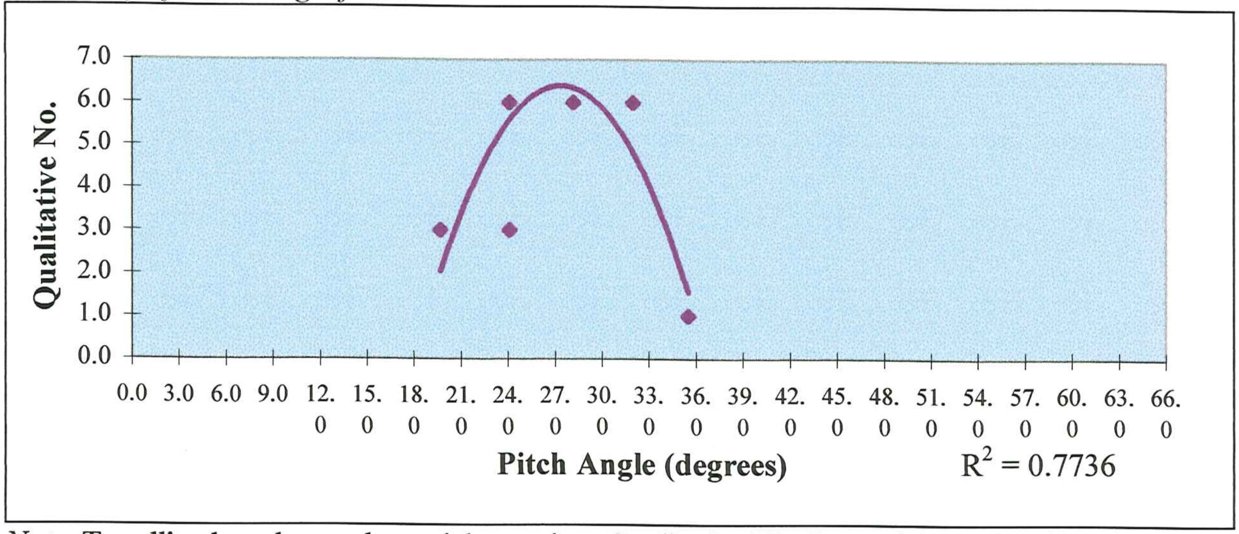
# Appendix I

In order to better determine the variability and significance of the behavioral changes in relation to pitch angle and pi-number, a simple plot was made of pitch angle verses the coded number, behavior. As the pitch angle increased, so did the qualitative number until the relation peaked at 27.0$^0$, and then begun to decrease with each increase in angle. When analysis was applied to this inverted "U" relationship, a r of .88 was found. In relation to $Pi_I$, the same inverted "U" is observed and r is even greater, .92. The system peaks at .30 pi-number, and it could be suggested that the relative riser height, $Pi_I$, influenced the behavioral changes more than pitch angle. However, caution should be used in attributing these differences as significant.

Chart 3

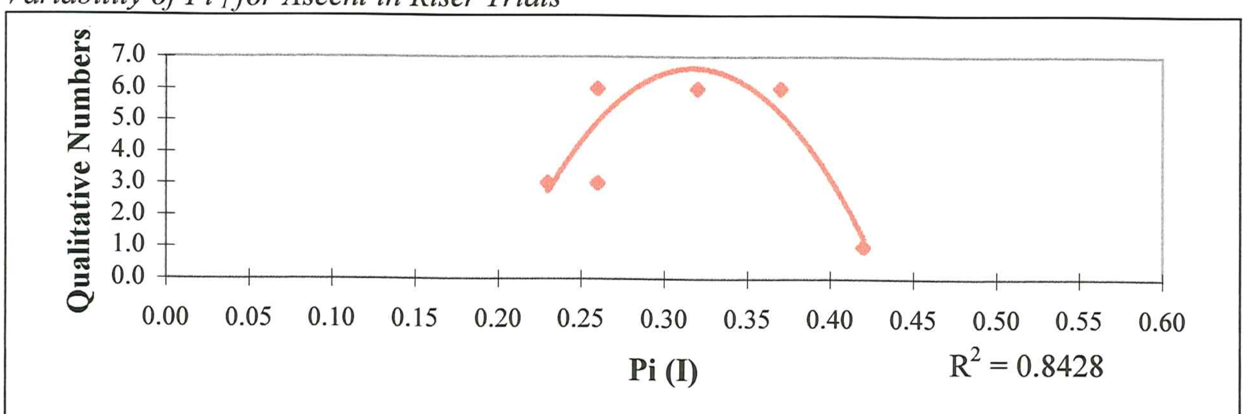
*Variability of Pitch Angle for Ascent in Riser Trials*




*Note.* Trendline based on polynomial equation. Qualitative No. Legend:1-Mark w/ handrail, 2-Mark w/ hands used for balance, 3-Mark, 4-Alter w/ handrail, 5-Alter w/ hands used for balance, 6-Alter

Chart 4

*Variability of $Pi_I$ for Ascent in Riser Trials*




*Note.* Trendline based on polynomial equation. Qualitative No. Legend:1-Mark w/ handrail, 2-Mark w/ hands used for balance, 3-Mark, 4-Alter w/ handrail, 5-Alter w/ hands used for balance, 6-Alter

## Appendix II

There was no presence of variability in the riser height descent trials. Neither pi-number nor pitch angle influenced the subject's system. Perhaps, other affordances such as safety, balance, and even eccentric muscular development are the main limiters of the subject's ability.

Chart 5
*Variability of Pitch Angle for Descent in Riser Trials*

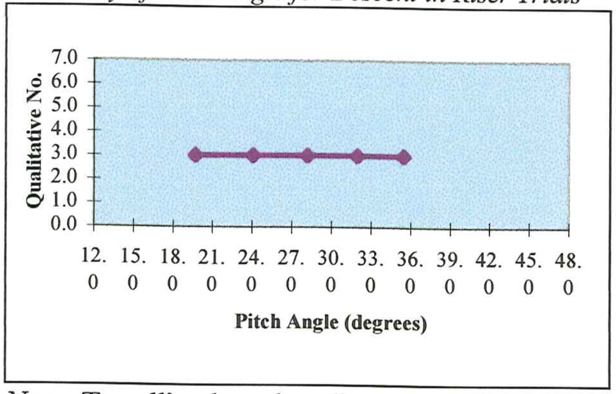
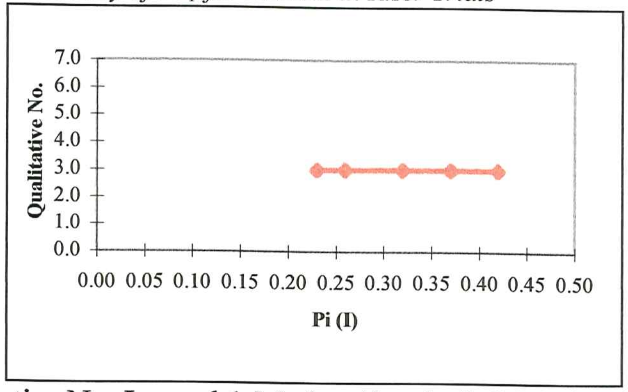



Chart 6
*Variability of Pi $_I$ for Descent in Riser Trials*



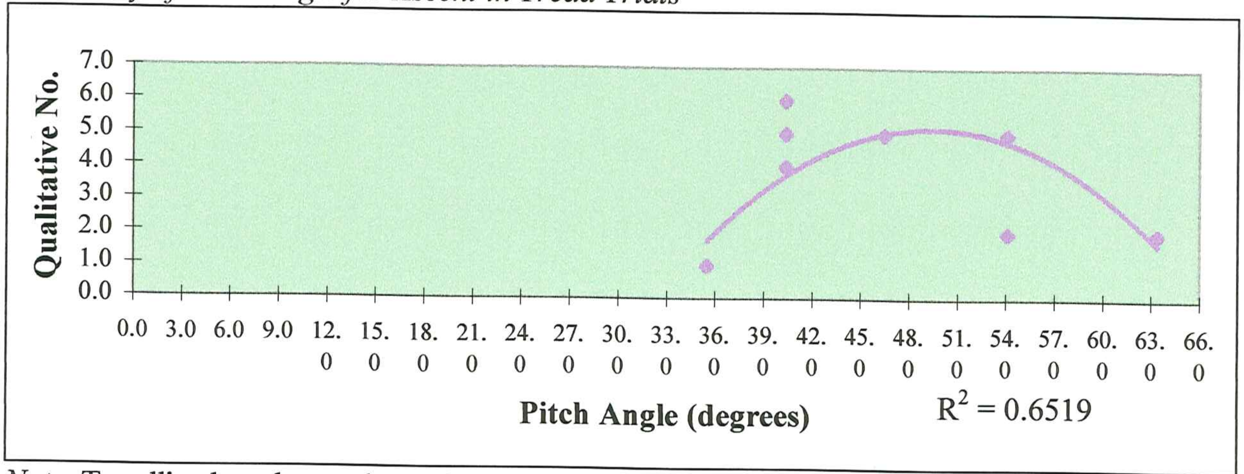

*Note.* Trendline based on linear equation. Qualitative No. Legend:1-Mark w/ handrail, 2-Mark w/ hands used for balance, 3-Mark, 4-Alter w/ handrail, 5-Alter w/ hands used for balance, 6-Alter

## Appendix III

Tread depth ascent variability yielded an inverted "U", similarly to the riser height ascent system. However, this system appears to have a range of $45.0^0$ to $54.0^0$ at its peak, which is consistent with what Maraj *et al* (1999) found. R was determined to be .81, and it is possible that even more trials or a larger population could continue and even strengthen the significance. The same is true for the pi-number analysis, but this system does peak at a set number of .40 pi-number and not a range. Its r value is approximately .89, which if there really is any significance between the two r's suggests that leg length in relation to tread depth (Pi $_{II}$) influences the perception-action coupling more than the pitch angle.

Chart 6

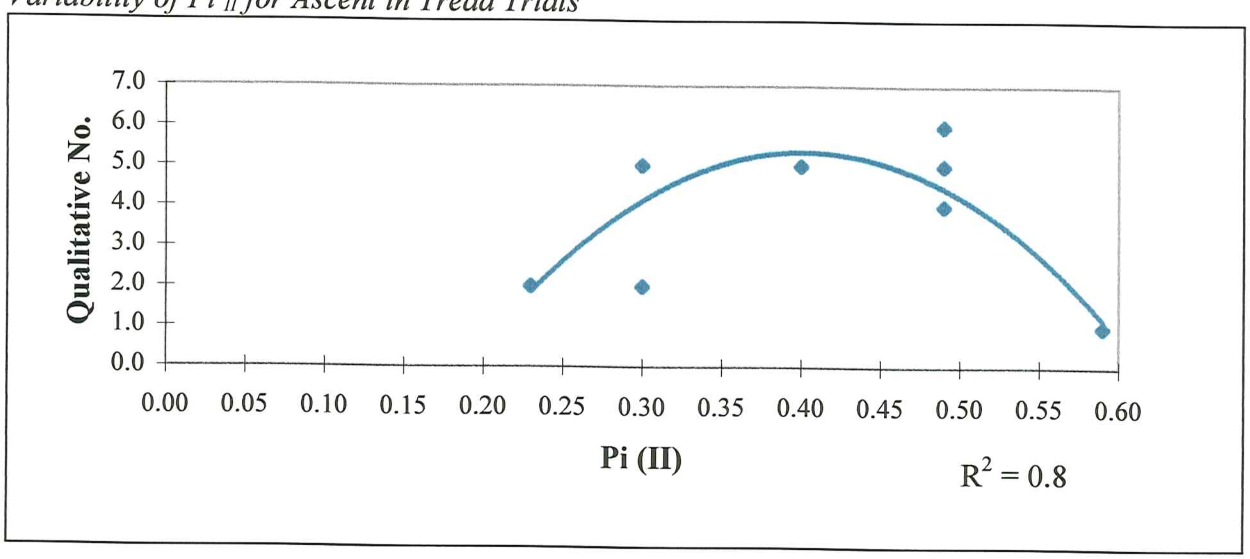
*Variability of Pitch Angle for Ascent in Tread Trials*




*Note.* Trendline based on polynomial equation. Qualitative No. Legend:1-Mark w/ handrail, 2-Mark w/ hands used for balance, 3-Mark, 4-Alter w/ handrail, 5-Alter w/ hands used for balance, 6-Alter

Chart 7

*Variability of Pi $_{II}$ for Ascent in Tread Trials*




*Note.* Trendline based on polynomial equation. Qualitative No. Legend:1-Mark w/ handrail, 2-Mark w/ hands used for balance, 3-Mark, 4-Alter w/ handrail, 5-Alter w/ hands used for balance, 6-Alter

# Appendix IV

Descent for tread depth appears to have some variability, but both r's are low (.63 and .73). The variability is caused by outliers in the system, which were the pitch and relative tread depth conditions for the only change in behavior during the trials (See Results and Discussion, pg. 9).

Chart 8

*Variability of Pitch Angle for Descent in Tread Trials*

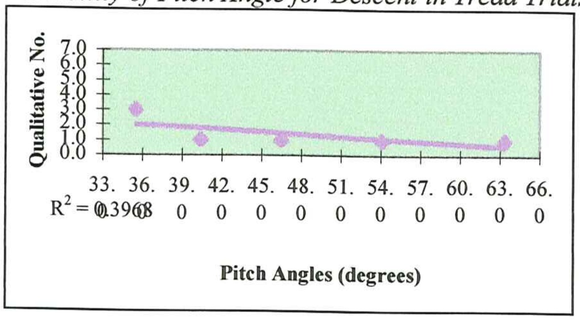
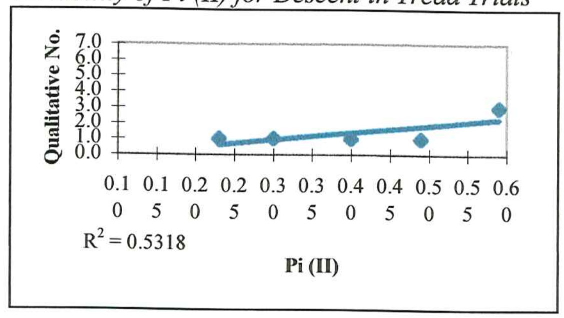



Chart 9

*Variability of Pi (II) for Descent in Tread Trials*




*Note.* Trendline based on linear equation. Qualitative No. Legend:1-Mark w/ handrail, 2-Mark w/ hands used for balance, 3-Mark, 4-Alter w/ handrail, 5-Alter w/ hands used for balance, 6-Alter