QUANTIFICATION OF THREE-DIMENSIONAL SPACE UTILIZATION
IN UNSTRUCTURED HUMAN MOVEMENT

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By
Shirley Jeanne Ahrens, B.S., M.S.

* * * * * *

The Ohio State University
1974

Reading Committee:  
Professor Naomi Allenbaugh
Professor Lewis Hess
Professor Seymour Kleinman

Approved By

[Signature]
Adviser
Department of Physical Education
ACKNOWLEDGMENTS

To those who have been closest and most responsive to the directions and interests of this investigation the writer expresses grateful appreciation. Warm thanks and gratitude are extended to Professor Naomi Allenbaugh whose perceptive and human understanding has been a positive force in helping to elaborate the writer's ideas. To Professor Lewis Hess, dissertation adviser, goes commendation for his moral support throughout this study. Gratitude is extended to Dr. Seymour Kleinman, Department of Physical Education, and Dr. Harold Trimble, Department of Mathematics and Science Education, Graduate School appointee, for their willing and gracious service as readers and oral interrogators. Appreciation is expressed to Mrs. Ronda Clapsaddle, dedicated dissertation typist. To Professor Carl Balson, Department of Theatre Arts, Beloit College, goes thanks for his technical assistance with the television equipment. Finally, with a keen sense of indebtedness, recognition and thanks are accorded Professor Francis Gathof, Department of Economics, Beloit College, for invaluable assistance and continued guidance throughout the experimental, analytical and computer programming portions of this study.
VITA

December 20, 1940 . . . . . Born - Peoria, Illinois

1962 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>ii</td>
</tr>
<tr>
<td>VITA</td>
<td>iii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>ix</td>
</tr>
<tr>
<td><strong>CHAPTER</strong></td>
<td></td>
</tr>
<tr>
<td>I. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Statement of the Problem</td>
<td>1</td>
</tr>
<tr>
<td>Movement in Perspective</td>
<td>1</td>
</tr>
<tr>
<td>Structure of Human Movement</td>
<td>5</td>
</tr>
<tr>
<td>Space and Spatial Elements of Movement</td>
<td>5</td>
</tr>
<tr>
<td>Time and Temporal Elements of Movement</td>
<td>12</td>
</tr>
<tr>
<td>Force Elements of Movement</td>
<td>13</td>
</tr>
<tr>
<td>Definition of Terms</td>
<td>16</td>
</tr>
<tr>
<td>Hypotheses</td>
<td>17</td>
</tr>
<tr>
<td>Assumptions</td>
<td>17</td>
</tr>
<tr>
<td>Delimitations</td>
<td>18</td>
</tr>
<tr>
<td>II. REVIEW OF LITERATURE</td>
<td>19</td>
</tr>
<tr>
<td>Non-Electronic Methods of Recording Human Movement</td>
<td>19</td>
</tr>
<tr>
<td>Literature Related to Dance and Movement Notation Systems</td>
<td>19</td>
</tr>
<tr>
<td>Literature Related to Qualitative Methods of Movement Analysis</td>
<td>37</td>
</tr>
<tr>
<td>Measurement Techniques Used in Analyzing Spatial Aspects of Human Movement</td>
<td>42</td>
</tr>
<tr>
<td>Human Movement Data Reduction Methods Using Computer Systems</td>
<td>47</td>
</tr>
<tr>
<td>Photographic Methods of Recording and Analyzing Human Movement</td>
<td>51</td>
</tr>
<tr>
<td>Literature Related to Single Camera Cinematography</td>
<td>51</td>
</tr>
<tr>
<td>Literature Related to Stereophotogrammetry</td>
<td>54</td>
</tr>
<tr>
<td>Literature Related to Multiple Camera Cinematography</td>
<td>55</td>
</tr>
<tr>
<td>Summary</td>
<td>62</td>
</tr>
</tbody>
</table>
CONTENTS (continued)

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>DEVELOPMENT OF THE ANALYTIC METHOD AND VALIDATION PROCEDURES</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>III.</td>
<td>Theory of Spatial Coordinates</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>Validation Procedures</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Preparation of the Video-Taping Site</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>Subjects</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>Movement Task</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td>General Taping Analysis Techniques</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td>Treatment of the Data</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td>Judges' Ratings of the Taped Movement Task</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td>Pilot Study</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>Reliability of Tape Analysis Procedures</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>Data Processing and Calculation of the Spatial Measures</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>Reliability of Spatial Measures</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td>Level of Significance</td>
<td>88</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IV. DISCUSSION AND ANALYSIS OF DATA</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability of Tape Analysis</td>
<td>89</td>
</tr>
<tr>
<td>Judges' Ratings of the Taped Movement Task</td>
<td>92</td>
</tr>
<tr>
<td>Pilot Study</td>
<td>94</td>
</tr>
<tr>
<td>Percentage Loss in Data</td>
<td>95</td>
</tr>
<tr>
<td>Rank Order of the Means of Combined Spatial Direction Change</td>
<td>100</td>
</tr>
<tr>
<td>Means of Trials 2-5 of Combined Spatial Direction Change for Each Subject</td>
<td>102</td>
</tr>
<tr>
<td>Means of Trials 2-5 of Combined Spatial Direction Change for Each Group</td>
<td>102</td>
</tr>
<tr>
<td>Conclusion</td>
<td>102</td>
</tr>
<tr>
<td>Validation of the Space Utilization Measures</td>
<td>105</td>
</tr>
<tr>
<td>Trend Analysis and Reliability Estimates of the Space Utilization Measures</td>
<td>116</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summary</td>
<td>124</td>
</tr>
<tr>
<td>Conclusions</td>
<td>127</td>
</tr>
<tr>
<td>Recommendations</td>
<td>128</td>
</tr>
</tbody>
</table>
CONTENTS (continued)

APPENDIXES

A. ACTIVITY BACKGROUND QUESTIONNAIRE ............................ 131
B. INSTRUCTIONS FOR PERFORMANCE OF MOVEMENT TASK .......... 132
C. GUIDELINES TO JUDGES FOR EVALUATING VIDEO-TAPES ........... 133
D. MEAN SCORES OF TRIALS 2-5 ON HORIZONTAL CHANGE, VERTICAL
   CHANGE, DEPTH CHANGE AND THEIR WEIGHTED COMPOSITE ....... 135
E. RAW SCORES BY TRIAL ON SPACE UTILIZATION MEASURES ......... 136
F. SOURCE LISTING OF COMPUTER PROGRAM ........................... 138

BIBLIOGRAPHY ........................................................................ 142
# LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. A SUMMARY OF INTER-OBSERVER RELIABILITY COEFFICIENTS</td>
<td>90</td>
</tr>
<tr>
<td>2. A SUMMARY OF INTRA-OBSERVER RELIABILITY COEFFICIENTS</td>
<td>90</td>
</tr>
<tr>
<td>3. SUMMARY OF ANALYSIS OF VARIANCE FOR THE HORIZONTAL SPATIAL COORDINATE (x)</td>
<td>91</td>
</tr>
<tr>
<td>4. SUMMARY OF ANALYSIS OF VARIANCE FOR THE VERTICAL SPATIAL COORDINATE (y)</td>
<td>91</td>
</tr>
<tr>
<td>5. SUMMARY OF ANALYSIS OF VARIANCE FOR THE DEPTH SPATIAL COORDINATE (z)</td>
<td>92</td>
</tr>
<tr>
<td>6. JUDGES' RANKINGS OF SUBJECTS WITHIN EACH PREVIOUSLY JUDGED CRITERION GROUP</td>
<td>93</td>
</tr>
<tr>
<td>7. PERCENTAGE LOSS PER GROUP OF VERTICAL, HORIZONTAL, AND DEPTH CHANGE DATA ACROSS VARIOUS INTERVALS</td>
<td>96</td>
</tr>
<tr>
<td>8. MEAN AND RANGE OF THE PERCENTAGE LOSS PER GROUP IN COMBINED VERTICAL, HORIZONTAL, AND DEPTH CHANGE FOR VARIOUS INTERVALS</td>
<td>98</td>
</tr>
<tr>
<td>9. SUMMARY OF ANALYSIS OF VARIANCE OF WEIGHTED COMPOSITE SCORE</td>
<td>108</td>
</tr>
<tr>
<td>10. A SUMMARY OF THE SCHEFFE TEST FOR SIGNIFICANCE OF DIFFERENCES BETWEEN GROUP MEANS FOR WEIGHTED COMPOSITE CHANGE SCORES</td>
<td>108</td>
</tr>
<tr>
<td>11. SUMMARY OF t VALUES COMPARING INDIVIDUAL SUBJECTS AND CRITERION GROUP MEANS</td>
<td>110</td>
</tr>
<tr>
<td>12. RANKINGS ON SPACE UTILIZATION AND LINEAR DISTANCE TRAVELED</td>
<td>111</td>
</tr>
<tr>
<td>13. RANKINGS ON SPACE UTILIZATION AND LEVEL CHANGE</td>
<td>112</td>
</tr>
<tr>
<td>14. RANKINGS ON SPACE UTILIZATION AND LEVEL RANGE AS A PERCENTAGE OF SUBJECT'S HEIGHT</td>
<td>112</td>
</tr>
<tr>
<td>TABLE</td>
<td>DESCRIPTION</td>
</tr>
<tr>
<td>-------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>15.</td>
<td>RANKINGS ON SPACE UTILIZATION AND PERCENTAGE OF FLOOR GRID SHIFTS</td>
</tr>
<tr>
<td>16.</td>
<td>RANKINGS ON SPACE UTILIZATION AND PERCENTAGE OF ENTERABLE GRID SQUARES ENTERED</td>
</tr>
<tr>
<td>17.</td>
<td>RANKINGS ON SPACE UTILIZATION AND FLOOR PATTERN RANGE</td>
</tr>
<tr>
<td>18.</td>
<td>SUMMARY OF TREND ANALYSIS AND RELIABILITY COEFFICIENT FOR LINEAR DISTANCE TRAVELED, TRIALS 2-5</td>
</tr>
<tr>
<td>19.</td>
<td>SUMMARY OF TREND ANALYSIS AND RELIABILITY COEFFICIENT FOR LEVEL CHANGE, TRIALS 2-5</td>
</tr>
<tr>
<td>20.</td>
<td>SUMMARY OF TREND ANALYSIS AND RELIABILITY COEFFICIENT FOR LEVEL RANGE AS A PERCENTAGE OF SUBJECT'S HEIGHT, TRIALS 2-5</td>
</tr>
<tr>
<td>21.</td>
<td>SUMMARY OF TREND ANALYSIS AND RELIABILITY COEFFICIENT FOR PERCENTAGE OF POSSIBLE FLOOR GRID SHIFTS, TRIALS 2-5</td>
</tr>
<tr>
<td>22.</td>
<td>SUMMARY OF TREND ANALYSIS AND RELIABILITY COEFFICIENT FOR PERCENTAGE OF ENTERABLE GRID SQUARES ENTERED, TRIALS 2-5</td>
</tr>
<tr>
<td>23.</td>
<td>SUMMARY OF TREND ANALYSIS AND RELIABILITY COEFFICIENT FOR FLOOR PATTERN RANGE, TRIALS 2-5</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

FIGURE Page

1. VERTICAL PLANE REFERENCE ................................
2. VERTICAL PLANE REFERENCE ................................
3. HORIZONTAL PLANE REFERENCE ............................... 
4. LABAN STAFF .............................................. 
5. AN EXAMPLE OF LABANOTATION ............................... 
6. PRESIGNS INDICATING DIFFERENT PARTS OF THE BODY .......
7. LABAN'S EFFORT MODEL .................................... 
8. LAYOUT OF TAPING SITE .................................... 
9. SIDE VIEW OF PERFORMER ILLUSTRATING DISTORTION FROM 
   CAMERA LENSES .............................................
10. CARTESIAN COORDINATE SYSTEM ............................
11. MEAN PERCENTAGE LOSS OF SPATIAL DATA FOR EACH GROUP 
    FROM 2-4 SECONDS, 2-6 SECONDS, 2-8 SECONDS, 2-10 
    SECONDS, AND 2-15 SECONDS ..............................
12. RANK ORDER OF THE MEAN OF COMBINED VERTICAL, HORIZONTAL, 
    AND DEPTH CHANGES FOR EACH SUBJECT AT EACH INTERVAL 
    (TRIALS 2-5) .............................................
13. MEAN OF COMBINED VERTICAL, HORIZONTAL, AND DEPTH 
    CHANGE FOR EACH SUBJECT AT EACH TIME INTERVAL (TRIALS 
    2-5) ....................................................
14. MEAN OF COMBINED VERTICAL, HORIZONTAL, AND DEPTH 
    CHANGE FOR EACH GROUP AT EACH TIME INTERVAL (TRIALS 
    2-5) ....................................................

ix
CHAPTER I
INTRODUCTION

Statement of the Problem

This study proposed to develop and validate a method for measuring the three-dimensional space utilization of unstructured movement. Four subproblems formed the substantive part of the investigation: (1) the development of video-tape analysis techniques to obtain necessary three-dimensional data; (2) the development of adequate mathematical corrections for variations in body part locations due to photographic perspective; (3) the programming of a suitable computer model for calculating the selected measures of space utilization; and (4) the experimental evaluation of the proposed space utilization measures to test their accuracy and adequacy.

Although the interpretation of given movements is the aim of most analytic studies, the present study was intended to develop an adequate method of analysis which may be applied in the future to analytic movement investigations and to exhibit a model for the quantitative analysis of other movement components.

Movement in Perspective

In order to perceive the significance of this study, the discipline of general movement and, more specifically, the structure of human movement requires exploration.
Movement is the sign of all living organisms; human species, animals, plants, and all living organisms from the smallest microplasms to the largest cells manifest their existences through movement. It is their essential characteristic in any moment from conception to death. At the opposite extreme in scale are the colossal forms of movement which are almost beyond man's capacity to conceive or imagine; the universe involves ceaseless movement. Nothing, in fact, within any kind or scale of existence known is still.

Movement is, then, the basic experience of existence. Movement, both internal and external, is a vital component of life. Therefore, all behavior is movement, since there is no act without movement. Experiences of movement delineate the sequence of events in a temporal relationship, and the experiencing of the movement inherently involves the body. Man not only accomplishes his life's tasks through the medium of movement; moreover, movement provides an important means of expressing his ideas and feelings. Movement often takes the place of verbal communication; it is the link between man's intentions and their realization through action.

Laban has termed movement the "most important factor of our existence." He continues by stating:

Movement in itself is a language in which man's highest and most fundamental inspirations are expressed. We have forgotten not only how to speak this language, but also how to listen to it....

---

Thus, man communicates to the world through movement. An individual's movement is uniquely his own and representative of his very inner core of selfhood. Movement is one of man's basic expressions to other men—a three-dimensional language that bridges his personal outlook and his environment. Man continuously expresses himself through various modes in an effort to relate to the surrounding world, and ultimately to self. Movement is a statement of that interpretation and intentionality toward life. As the fundamental and essential quality of life, movement emerges as man's supreme medium of expression and communication. To paraphrase Moholy-Nagy, one can never experience movement through descriptions. Explanations and analyses are at best an intellectual preparation. They may, however, encourage one to make a direct contact with movement.2

The sense of movement is anchored to man's unconscious sense of bodily weight. Walking, standing, sitting, running, eating, reading, and sleeping are all performed with a continual holding, balancing, and maneuvering of one's bodily weight. An individual's inherent skill in the timing and control of movement is vital to existence.

Movement is classified on six levels in Harrow's hierarchical model of learning in the psychomotor domain.3 Level six, the highest level, includes "nondiscursive communication" which is subdivided into


"expressive movement" and "interpretive movement." While expressive movement includes the forms of communicative movement ranging from posture and carriage to facial expressions and gestures, interpretive movement is defined as the aesthetic and creative movement which represents the highest level of movement development, art forms.  

This kind of interpretive movement elicited by an improvisational task is precisely what this study employed. Interpretive movement invents and controls movement in such a way that the mover learns to share the external picture of what the body looks like with the important reflection of what it feels like. The improvisational task is more than doing something; it utilizes movement that comes from within; it allows for the direct, immediate, and spontaneous expression of intimate feelings; it is motion that matters.

This fundamental nature of movement behavior is suggested by Perl:

Next to language, movement of our body or its parts is our most common means of expression. In the development of the human race, expression by movement preceded the use of organized language and the same is true of the development of the individual--it is quite possible that, because our earlier reactions were freely expressed movement, the expression by movement continues to be more free, less inhibited than verbalization.

It is apparent from the discussion that movement is universal, and that without movement there would be no life or progress.

4Ibid., p. 93.

According to science, all matter is reducible in the final analysis to energy expressing itself through motion. In a materialistic interpretation, then, it can be assumed that movement is an individual's expression of force in time and space. With this in mind, it is important that physical educators and movement researchers, in general, gain an understanding of not only the quality of a performance, but also an understanding of the use of each of these components in terms of extent and range. It is with that very goal in mind that this study was undertaken to devise a new systematic method for assessing the extent and range of the spatial component in movement.

Structure of Human Movement

A simplistic overview of the structure of movement may provide the reader with a framework for understanding the specific element of movement to which this study is directed and limited. Since movement is an expression of force in time and space, specific aspects of space, of time, and of force must be examined.

Space and Spatial Elements of Movement

Space is limitless. It has no boundaries; it extends in all directions. Objects in space have measurable limits, and differentiation can be made between areas of space occupied by objects and empty space. Object-occupied space may be referred to as positive space, while empty space may be identified as negative space.

One dictionary defines "space" this way: "a limited extension in one, two, or three-dimensions: a part marked off or bounded in some
way: distance, area, volume." Harvey Carr's definition describes the spatial attributes of objects: "their size, shape, stability, motility, and their distance and directional location in reference to each other and to the perceiving subject." Space may be thought of as a locality in which changes take place. The locality is not simply an empty room, separated from movement, nor is movement an occasional happening only. Space is a superabundance of simultaneous movement; and movement is a continuous flux within the locality itself. Laban identifies this fundamental aspect of space by stating that "space is a hidden feature of movement and movement is a visible aspect of space."  

Man is always subjected to a spatial sensation as he is always in an enclosed space. It is possible to describe space with words and illustrate it with drawings and photographs, but all these give only a poor idea of space. Representations do not give one the experience of spatial sensation. The sensation of space cannot be compared, for instance, with the idea a reproduction gives of a painting. While a painting, which is a two-dimensional creation, is reproduced in a two-dimensional reproduction, the reproduction produces a sensation of the same order as the original painting. Movement, a three-dimensional


spatial phenomenon, can only be hinted at by a two-dimensional repre-
sentation such as a photograph. While looking at such a representation,
spatial sensation cannot possibly be experienced, only imagined.
Space is properly appreciated by man, himself, moving in it and
experiencing its sensation.

The human body as a three-dimensional form occupies space. Its
spatial limits are the boundaries of the moveable bodily parts. The
measurable relationship of the bodily parts relative to each other at
any moment is the positive space shape of the body, its position. As
long as the bodily parts retain their same space measurements, the
body is holding its position. Its motion is arrested. Changes in the
measurements of positive space indicate the body is in motion. The
description of the spatial changes reveals the spatial design of the
movement.

Every movement has definite spatial characteristics which may be
perceived visually as well as kinesthetically. The most basic of
these are: distance or amplitude, direction, plane, level, and shape.
These are relative conceptions. The position of a moving body (or the
direction, distance, plane, level, or shape of its movement) has mean-
ing only in relation to something.

A movement may be defined as one of the following four basic
types of spatial relationships:

1. In relation to the surrounding space, its position may be
central, peripheral, background, foreground, top, bottom, side; its
direction may be centrifugal, centripetal, from background to foreground, from side to side, top to bottom.

2. In relation to points within the surrounding space, its position may be beside, behind, in front of; and its direction may be toward, away from, around, over, under.

3. In relation to the earth, a movement may be vertical, horizontal, oblique.

4. In relation to the structure of the moving body, a movement may be forward if the front of the body is leading, or backward if the back of the body is leading, etc.

The first element of space to consider is that of distance. Distance is the amount of space between two points in space. The two points may be arbitrarily selected for measurement. The body or any of its parts may represent a point in space. The position of a part is its position in space for purposes of spatial measurement. Successive different positions of a selected bodily part may be represented by a sequence of space points. The measurement between successive points is the distance covered by the displacement of the part or parts.

The measurement may be in units of angular degrees, as measured by a protractor, or in units of linear inches or feet, as measured by a ruler or caliper. The space measured may be positive space or negative space or both.

The distance covered by a bodily movement is revealed in the amplitude of displacement of the bodily part or parts. The amplitude
is governed by the range of the joint action and the length, size, and shape of the part or parts displaced. The joint action range may be given in degrees of angular distance. Amplitude also includes the linear or straight line measurement expressed in inches or feet. The points selected for measurement may be a point on the bodily part in its beginning position and that same point when the bodily part is in a succeeding position. The change in location of the total body as a result of locomotor movements may be measured by selecting the base of support, center of gravity, or some specific body part and by measuring the change between succeeding positions in linear distance.

...in every movement that is made, direction is taken, and distance covered in space...⁹

Another aspect of space to consider for definition is direction. Direction may be defined as an imaginary line or path through space. The body or a bodily part in motion creates its own line in space. The line extends from the beginning point of the motion to the end of the motion. The imaginary line starts from a selected point on the body and flows to and through a series of designated points in space during the movement. This is considered the direction of movement.

Similar, yet distinct, is the meaning of direction in relation to the body. It refers to the relationship of given surfaces of the body to given surfaces of other objects or reference points in the environment. Bodily direction relates to an imaginary perpendicular line

emanating from a given surface of the body out into the environment, as the surface of the palm of a hand related to the floor, or to the wall, or to other body surfaces. Every movement of the body follows a certain direction or path, and during a specific movement each body surface may be described in relation to its own direction during that movement.

A third aspect of space that is significant in defining a specific movement is that of plane. Plane is "a surface of such nature that every straight line joining two of its points lies wholly in the surface." Plane must conform to four right angled directions and any diagonals related to the four directions. The vertical plane in reference to the earth may be related to directions up-down-forward-back or up-down-right-left, as shown in Figures 1 and 2 respectively. The horizontal plane may be related to forward-backward-left-right, as diagramed in Figure 3. The figures are diagramed as a forward view by the observer.

The plane of bodily action relates to the bodily planes, sagittal, frontal, and transverse. When the body is standing upright the sagittal plane directions and the frontal plane directions relate to the two given vertical planes of the earth. The transverse bodily plane relates to the horizontal directions. However, the bodily action planes must be considered with reference to the body's longitudinal line, as head-foot related to forward-backward and right-left. When the body is in a prone position, the longitudinal line relates to the horizontal earth's plane. Bodily action planes may be considered independently of the earth's horizontal and vertical axes.

A bodily action plane is the imaginary plane of displacement of a bodily part resulting from a particular type of joint action. The displacement is at right angles of the axis of rotary motion at the joint.

Another aspect of space to consider for further definition of a movement is that of level. Level may be defined as the altitude or height or vertical distance from the floor. If a point on the body in motion remains the same vertical distance from the floor, then the bodily point may be said to be in motion at a constant level. If the point changes its vertical distance or altitude with relationship to the floor, then the bodily point may be said to be changing its level in space.

The changes in the elements of space, distance or amplitude, direction, plane, and level, characterize the spatial design of any movement or sequence of movements. This spatial design may be considered as the final aspect of space to consider for abstraction and
definition purposes. The shape of a movement through space, or its path over the floor, can be basically described as either curved or straight, rounded or angular. The shape of the body parts and the shape the body is able to make in space constitute this visual spatial element. All spatial elements cover one set of relationships whose qualities define or contribute to a given movement's form. Any change in the spatial characteristics alters the movement's design aspects. Changes in amplitude or distance, direction, level, and plane will alter or vary the shape and path of a movement to some degree.

**Time and Temporal Elements of Movement**

As mentioned previously, all movement takes place in time. Like space, time is infinite. Man has conceived of various systems and units for measuring time. A particular set of relationships will be examined whose quantities further define movement within the temporal aspect.

Time applied to the joint action sequence affects the quality of the movement of the spatial design within a movement phrase.

...But in the perception of muscular sensations in movement the factors of main concern are time and stress. For no matter what distance is covered or what direction taken, time is consumed and effort is expended.11

---

Time-length, here, means duration. It refers to how long the movement phrase lasted during its execution. It may refer to the entire movement phrase or to an individual part of the total form. The time-pattern of a movement phrase is the sequence of duration intervals of each of the parts. The sum of the duration intervals, then, equals the duration of the whole movement phrase.

The attribute of time-length or duration applied to a bodily part controls the speed quality of the motion of that part. The action range or distance covered by the movement divided by the duration of the movement defines the rate of speed characteristic of the displaced part. Given the same movement range for two actions, the action with the longer duration will have a slower rate of speed, and conversely, the action with the shorter duration will have a faster rate of speed. In the execution of any given movement, care must be taken in its repetition to keep the position points in space coordinated with the points in time. Any discrepancy will alter the duration of the movement, disturb the coordination, and delay the automaticity stage of rhythm. With the consistency in the space-time coordination of a movement or movement phrase, the muscles will assume the responsibility for their repeated activity as they learn the proper time proportioning.

**Force Elements of Movement**

Force is a continuous stress. The unit of force in considering movement may be called the impulse. The basic characteristic of
impulse is alternation of stress and un-stress. Rhythm is the inner organization of the impulse, which creates the living relationship between the points of stress and the points of un-stress. The dominant element of rhythm is force, which determines the nature of the impulse and its intensity. Co-existent is the element of time, which determines the period of the impulse and its duration. Finally, the element of space, qualified by both the other two, determines the position of the impulse and its direction.

Moreover, it is only when these two factors of time and flow of energy are properly related, or 'tuned' that efficient and satisfying movement results...Time and stress, then, are the distinguishing characteristics of muscular sensations by which we can know movement...Rhythm is measured energy. It is action and rest—control and release.  

The forces whose interaction contribute to the quality of a given movement are (1) the pull of muscle groups in various directions and various amounts of strength interacting with (2) the downward pull of gravity, and with (3) the momentum of a moving part pulling in the direction of its motion. The timing and strength of muscle action determines the rhythm and characteristic feeling or feedback quality of any movement. Muscle tension increases or decreases as the interacting forces of gravity and momentum demand varying degrees of muscle effort to effect and control the movement. The tension amount is subject to the weight of the displaced part and the direction-distance-duration specifications of any movement's form.

---

12Ibid., pp. 5-6.
The timing of the muscle action, whether contraction or relaxation, must be in anticipation of the direction and distance to be covered in space and the formal duration specifications in time of the displaced part. It is the timing and strength of the muscle action pulling, or releasing pull, on the bones of the resisting moveable parts which is responsible for the rhythm experienced in the movement.

By definition, movement is a change of place or position in space involving energy expenditure and the consumption of time. With reference to human movement, the term is restricted to gross or easily observable voluntary change, implying that the distinction between "moving" and "not moving" should be regarded as one of degree and not of kind.

In this study, the movement events which are to be analyzed are the relations and the changes of relation to the human body in three-dimensional space. Such relations will be called positions. A change of relation will be called movement. Movement is described by the path or the way the body changes its positions in space. It is the movement between the positions in space that will be described by locating the spatial coordinates of the body within an established time interval. Therefore, the purpose of the study is to analyze the body as a visual phenomenon by devising a system to measure the physical phenomena in the world of spatial location.
Definition of Terms

1. Movement Task. The unstructured, free, improvisational movement individually created within the temporal and spatial restrictions provided.

2. Unstructured Movement. Bodily movement which has no prescribed pattern of organization, no imposed theme or prescribed movements, and no objects or props present for use.

3. Improvisational Movement. Movement which is individually composed and arranged on the spur of the moment without previous preparation.

4. Space Utilization. A general term used to describe the extent and range of individuals' movements within three-dimensional space. For the specific components of space utilization used in this study, refer to the definition of "spatial dimensions."

5. Spatial Dimensions. The following quantitative measures were developed as being indicative of an individual's space utilization:

A. Linear Distance Traveled - the cumulative linear distances relative to the depth and horizontal coordinates between consecutive spatial locations obtained at four-second intervals.

B. Level Change - the total linear vertical change in the body's level which at any point in time was calculated to be the distance from the floor to the highest body point.

C. Level Range as Percentage of Subject's Height - the ratio of the difference between the maximum and the minimum levels attained for each trial and the subject's height.
D. Percentage of Possible Floor Grid Shifts - the ratio between the sum of the number of location changes a subject made from one grid square to a different grid square during each trial and the number of possible location changes a subject could have made during a trial based upon the four-second interval sampling.

E. Percentage of Enterable Grid Squares Entered - the ratio between the number of distinct or unique grid squares entered by a subject and the number of possible grid squares available for entry within the time points sampled.

F. Floor Pattern Range - the greatest difference between any two spatial locations relative to the depth and horizontal coordinates.

Hypotheses

The following hypotheses will be investigated:

1. A reliable and accurate method can be devised for the location of spatial coordinates in three dimensions.

2. Applying the proposed method to unstructured movement, spatial dimensions of movement can be quantified to assess validly space utilization.

3. The selected space utilization measures will exhibit a high reliability as reflected in the Movement Task trials.

Assumptions

It was assumed that:

1. Because the study was designed to prevent data contamination, subject-to-subject interactions were non-existent.

2. The unstructured Movement Task employed would elicit gross movement responses.
Delimitations

This study was limited to volunteer college men and women enrolled in Beloit College during the Third Term of 1971.

As in most experiments involving human subjects, it was impossible to control all variables, such as mood, state of fatigue, etc.

The selected aspects of space utilization analyzed in this study were limited to the extent and range of total body movement along each of the spatial axes.
CHAPTER II

REVIEW OF LITERATURE

Literature pertinent to the present study is reviewed in this chapter. The reported research deals with dance and movement notation systems as well as qualitative methods of recording and analyzing human movement. Photographic methods including single camera cinematography, stereophotogrammetry, and multiple camera cinematography to record and analyze human movement are reviewed. Also presented are specific measurement techniques used in analyzing spatial aspects of human movement and computer methods for human movement data reduction. Specific emphasis is placed upon the aspects of these investigations which are directly related to the development of the proposed methodology used in analyzing spatial dimensions of improvisational movement.

Non-Electronic Methods of Recording Human Movement

Literature Related to Dance and Movement Notation Systems

Individual styles of treating movement in dance forms necessitated that European dance masters develop methods of notating and recording dances. To keep alive traditions, the repertoire, and the ideas of movement of a particular school of the dance, dance masters have struggled with attempts to reproduce movement by means of the sketch, the symbol, and the dotted line. From Michel Toulouze¹, one of the

pioneer dance masters to record his observations, to Arthur Murray, whose studios cater to millions of aspiring dancers, the professional dance masters have experimented with ways of permanently recording their routines.

One of the earliest\(^2\) is a system called Letter Substitution, popularized by the French master Arbeau in 1588.\(^3\) In Arbeau's arrangement he listed all the steps that were used in the dances of the period, something made possible by the fortunate fact that each step had a name. In notating his dances Arbeau used the initial letter of a given step to take the place of a written notation of the whole step, since in his time the steps were still uncomplicated and quite restricted. Thus, the amount of time needed to notate the dance was shortened considerably.

Letter Substitution is adequate, however, only when there is a complete vocabulary of dance terms to describe every single movement. A fully developed scheme of notation should cover not only the dancer's steps, but also the floor pattern—that is, the path the dancer traces while going through the dance.

\(^2\)For a full discussion of early masters see the following references:

\(^3\)Thoinot Arbeau, *Orchesography* (Dance Horizons, Ind., 1967).
Interest in floor pattern became intensified in the eighteenth century, when the court ballets grew more complex. Complicated circling, squares, twining and serpentine formations began to dominate the simple steps, and it became more important to stress position on the floor than individual movement. Ballet masters like Peuillet and LaCuisse were responsible for popularizing a newer form of notation. Peuillet created a system using characters and figures in basic dance positions accompanied with floor pattern symbols. The notation was not explicit as to the direction or duration of a movement, although steps, jumps, and movements of the head, arm, and knee were indicated. In the LaCuisse system a series of dotted lines traced out the paths of the dancer. Little geometric symbols indicated whether the performer was a man or woman; small crossed lines showed whether or not the dancers held hands during the performance of each figure.

These track drawings had many advantages. The complete progress of the dancer could be traced, from the beginning to the end of a dance. Because the lines followed the actual path of the dancer, it was easy for the performer to reconstruct the dance by following directions. Moreover, a comprehensive picture of all the floor patterns aided in forming new and different figures. It would seem that this method is quite adequate when steps consist of simple walking or shuffling movements and when the patterns of the dances assume more

---

4Laban, "Introduction to Dance Notation," p. 98.
importance than individual motions of arm or leg. Track drawings would probably fail in recording the dances of other cultures where movements are concentrated in particular body parts and as such could not be notated with track drawings. Cultural dances of Africa, Polynesia, Japan and Modern Dance, as known in America, might defy analysis by this particular method.

The third era of notation developed somewhat later in the nineteenth century. Interest in the fluid motions of the classical Greek dance was revived, and great emphasis was placed upon individual body movements. To cope with the notation of a complex series of such movements, it was necessary to outline the body of the dancer in motion. St. Leon's publication (La Stenochor'egraphie, 1852) used all symbols and signs from the perspective of the spectator, contrary to previous methods. He notated each movement of a step with its corresponding body, head, and arm movement. All notation was written above the music; each movement was drawn above the note on which it was performed.

Further evidence of the closer relationship of dance and music can be found in the notation system developed in 1892 by Fladimer Stepanov, a Russian dance instructor at the Ballet Academy in St. Petersburg. The symbols of notation were placed between the five

---


lines of the musical staff resembling musical notation. The stem represents the upper part of the body when it is pointing up and the lower part of the body when it is pointing down. In place of a clef, a sign is drawn indicating the dancer's starting position. This notation system was incomplete, however. Using this system, reproductions of masterworks were based on the memories of the performance, a highly limiting factor in terms of both accuracy and temporal recall.

An influential notation system using musical notation was developed by the German, Bernard Klemm. Corresponding to the movements of the right and left foot, stems were drawn on the right and left side of the musical note; two stems were drawn if both feet moved. A variety of musical signs was used for the interpretation of knee bends, for toe and half toe steps, for back and forward, and also for sideways movement. Short verbal explanations added to the exactitude and comprehensiveness of the notation.

Zorn popularized the nineteenth century method called Stick Figures which he used to record several ballets, coordinating the motions of the dancers as shown by the stick figures with accompanying music. It is to be noted that in his track drawings, as in

7Laban, "Introduction to Dance Notation," p. 114.

8Laban, "Introduction to Dance Notation," p. 115.

St. Leon's method, the observer views the choreography as if he were one of the dancers. Stick figures are extremely adaptable, since they may give the complete routine of a dance or may be utilized to point out the significant movements of arm or leg. However, stick figures clearly have their limitations. It is difficult to use them to show floor pattern, and the method becomes clumsy when there are intricate steps or figures. If more than one dancer participates, and each individual performs different steps, it is awkward to try to reproduce all the movements.

The fourth era of notation, Twentieth Century, saw the rise of numerous attempts to revise and devise systems of dance and movement notation. Many of these were designed to suit the needs of the modern dance, with its complexities of body movement, its changes in rhythm, its elaborate floor patterns, its employment of large groups of dancers.

Early in the twentieth century Vaslav Nijinsky proposed a system of notation. According to Kirstein,

> It could be easily read as music. That is, a ballet composition could be preserved, similar to an orchestral score... He collaborated with a physician in order to make it anatomically feasible. Not only dance movement, but motions for sport, industrial activity, physical exercise could be simply recorded... It has never been published.¹⁰

Margaret Morris discussed her notation and its principles in a book on *Notation of Movement*.\(^{11}\) She explains that her own method might more correctly be called "the notation positions", for it is the position that the movement is leading to which is recorded. The movement itself is taken for granted, and is indicated by "transition" signs. Sketches of the positions in this system are well-defined, but the accompanying dance notation symbols fail to convey an articulate picture.

Sol Babitz, native American, discussed his *Outline of a New Method of Dance Notation* in the *American Dancer*. His scheme entails three major processes. As he states them, they are:

1. Observation—seeing or knowing movement.

2. Analysis—discriminating among the various aspects of the movement and deciding which one is essential for the adequate description of it.

3. Writing—describing the movement on the staff with as few symbols as possible.\(^{12}\)

Capitalizing on the need for a notation system, Babitz as a non-dancer invented his natural notation in a short period of time with little thought for refinement and simplification. It is one of the few methods appealing to the eye, but upon closer examination Babitz's method is grossly defective.


Other dancers who occupied themselves with the problem of notation are Craighead who developed a system of notating the modern dance and its technique, and Cross who advanced an idea to describe dance movements in kinesiological terms. Alwin Nikolais announced in 1948 his modification of the Laban system which he termed choroscript. Nikolais felt the inherent problems in Labanotation consisted of cumbersome and inflexible symbols which resulted in the system's lack of use. His revision adopted the musical staff and divided the body graph into two staves (extremity and trunk). The actions of the body were divided into three categories which he described as follows:

In peripheral movement the body member attached at one end by its joint extends out from that center like the radius of an imaginary sphere, the outward end describing the circumference. Rotary movement is the action of the body or body unit rotating within its own space. Locomotor movement is a complete shift to a new space.

Symbols representing time which were similar to musical notes were placed on the graph in the section where a given body unit was represented.

Another major notation system developed in the twentieth century was invented by Rudolf Benesh at the request of his dancer-wife. As described in his book, An Introduction to Benesh Movement Notation, 13


the system utilizes the five-line staff of music as the matrix for the human figure. A series of lines and other symbols trace the path of movement in space from one position to another for each of the following body parts represented by the five-line staff: the line of the head, the line of the shoulder, the line of the waist, the line of the knees, and the line of the feet. General direction of movement, pathways, rhythm, locomotion are included in the system. The expression marks of music are adapted to indicate the dynamics and effort qualities of movement.

The Eshkol-Wachman system disregards particular shapes of the body limbs when the movement of the body's longitudinal axis is abstracted from them. All limbs are treated as straight lines. The notation script includes two lines drawn on a page perpendicular to one another. The body is represented by the vertical line which is subdivided into six equal sections, each section representing one part of the body—left leg, right leg, the main body, right arm, left arm, and head. The horizontal line represents the flow of time. Equal divisions are marked off along this coordinate, and these vertical columns represent equal units of time. The particular abstractions of any movement that are notated include: type of circular, conical and non-conical movement; magnitude of movement in degrees; weight distribution; "light" and "heavy" limbs; vertical, horizontal


and intermediate plane movements; rhythmical time pattern; limb positions, base positions and rotations; floor pattern; simultaneous and auxiliary movements.

Rudolf von Laban, European choreographer, performer and dance theoretician, first described his notation analysis in a book, *Choreograph*, published in 1926, and expanded his system in later publications. Since the time of that incomplete description, the Bureau of Dance Notation has adapted with the approval of Laban some of the symbols and has simplified the system. Laban's notation system was the first method applicable not only to dance but to human movement in general, and thus is more universally used than any other system devised in the twentieth century. Because of the wide acclaim of Labanotation, a more thorough analysis will be presented here than has appeared for other notation systems. The system depends entirely on a small group of symbols; it is unique in that one symbol can show the step the dancer is performing, the direction he is following, the speed of the movement, and the approximate level.

The Laban system is based on the three-line vertical staff (see Figure 4) which is drawn under the accompanying melody for the dance. The staff represents the body of the dancer, the center line being the center line of the body, dividing right and left. Vertical columns on each side of the center line are used for the main parts of the body.

---


Movements of the legs and feet are written within the three-line staff, and movements of the torso, arms, and head are written outside. Within the staff there exists four major vertical columns (two on either side of the center line). Outside the three-line staff imaginary vertical lines, parallel to the main staff lines, provide additional vertical columns, as many as are needed. The two columns on either side of the support columns are reserved for movements of the legs, either in the air or on the ground. If the support columns are left blank, while there are notations in the leg column, this means that the dancer is performing some kind of jump.

The basic symbol in Labanotation is the rectangle, or modifications of the rectangle. The rectangle itself is the notation for any movement performed in place; that is, without moving in any direction. Direction is shown by notching the rectangle in various ways, after the manner shown in Figure 5. The symbol may also show time by establishing the beat before starting the notation. Thus, if a symbol is regarded as equal to the time taken up by a quarter-note, then a notation twice as long is equivalent to a half-note, and one-half the size indicates an eighth-note. In this way, the number of beats necessary to perform a given movement can be gauged by the length of the symbols.
Figure 4. Laban Staff. The staff is enlarged here to show the different uses of the columns.

Figure 5. An example of Labanotation. The notching of rectangles shows direction. The dot in each symbol shows middle level (walking stance here). 1) Both feet in position; 2) Right foot steps forward, left foot steps forward; 3) Right foot steps diagonally to the right, left foot diagonally to left; 4) Right foot steps to right, left foot to left; 5) Right foot steps diagonally back to right, left foot diagonally back to left; and 6) Right foot steps back, left foot steps back.

---

Labanotation symbols are also able to indicate level—that is, the direction of the movement being either upward, center, or downward. Separate notations are given for leg and arm levels. Level of legs is indicated in the following manner: "low level" usually refers to the movements performed with the feet on the floor and knees bent; "middle level" is used to describe leg movements performed in the usual standing position with the knees straight; "high level" refers to movements done with the legs extended and weight on the balls of the feet. Level is expressed by shading the basic symbol in different ways. For low, the symbol is completely blackened; for middle the symbol has a dot in the center, as in Figure 5; and for high, the symbol is filled in by diagonal lines. In reference to arm movements, notation of "high level" is made for movements above shoulder level, "middle level" for shoulder level arm movements, and "low level" for arm movements executed below shoulder level.

When it is necessary to refer to different or specific parts of the body, minute signs, as in Figure 6, are placed before the designated symbols. These presigns cover every joint or limb, and by using them, movement and direction of every sort can be plotted on the staff. In addition, the notation alphabet includes symbols for the various surfaces of the body (palm, face, chest, etc.); signs for touching, clapping, sliding, turning, floor patterns, and dynamics.
Figure 6. Presigns indicating different parts of the body.

It is not possible in this review to discuss fully all the devices used in Labanotation. For all its complexities, the system has the great advantage of relying upon a fixed set of symbols. It is however, by no means always the ideal system, despite its greater ability to record detail. For example, in attempting to notate some of the routines of the Seneca Indians with this method, while no difficulty was found in getting down the basic steps, yet because Seneca stressed floor pattern, it was soon apparent that it would be futile to go on repeating the same symbols. Pollenz\textsuperscript{21} finally reached the solution of writing down the basic steps in shorthand, and indicating the movement of the dance with track drawings.

Another great drawback of Labanotation is that it requires a long time to learn. Learning to read the symbols is comparatively easy, but it takes months of concentrated work to learn how to transcribe movement. An observer would have to be familiar with the dance movements before he set out to describe them, or he might find it difficult to transcribe the movements quickly enough. Prior knowledge of the movements to be analyzed was not available in this present investigation because of the improvisational quality of the Movement Task. Thus, the possibility of using Labanotation in this study was discarded as being too time-consuming and costly, among additional reasons to be pointed out later.

A more recent attempt to unite the spatial, motor, and temporal elements of dance was devised by Kurath. The ground plan or floor pattern in this system had the accepted simple solution of separate track drawings. The steps and gestures have sometimes been combined with the rhythmic beat and structure by substituting symbols for words and by writing them next to the staff, as in the ingenious Laban script. Comparative choreography required Kurath to devise a simpler and more graphic script than the Laban method. Steps and gestures of ethnic dances were notated by symbols and arranged on paper in the natural progression and floor pattern followed. The temporal elements (rhythmic beat) of the dance were integrated with the floor plan and the corresponding steps by rotating the staff on the page beneath

---

the notated symbols. The arrangement of this system is, however, somewhat inconvenient and cumbersome and necessarily limited by the notation system.

Mary Fee began devising a system of notation late in the 1960's based wholly on the anatomical structure of the body which provides a wider base for application. The manuscript page lists on the left side all moveable joints in five distinct body areas. In horizontal and vertical rows appear a printed design, called a "symbol of reference" ( ). This is truly the notation staff. The time value for each symbol of reference is changeable for the notater's needs. Three basic elements indicate the spatial aspect: 1) the longitudinal plane symbol element (plane and transverse direction indicator); 2) the flexion degree symbol element (degree of flexion and longitudinal direction); and 3) the rotation symbol element (indicative of the degree and direction of rotation). The general orientation of the body is provided by the following elements: 1) base of support indicating the support bearing segment; 2) contact point indicating surface contact with external object; and 3) body contact between two or more body parts. The notation system as published is still incomplete and can give only the spatial and temporal aspects of any one person's movement. However, the system is being expanded to include the aspects of force, dynamic qualities, and rhythm; and to include further symbol constructions necessary to include more than one person's movements.

To date, there is no system of notation that universally serves the needs in the fields of dance, education, neurology, anthropology, biomechanics, physical education, industrial quality control, or psychotherapy, to name a few. Labanotation has appeared to reach a wide usage. However, there are some evidences of dissatisfaction with the ingenious system. An example of the major concerns of its inapplicability is evident from the following:

Kinesiologists describe movements of parts of the body or of the body as a whole in terms of the planes and axes in which movements occur. It is possible that field workers in anthropology, who do not have the time or inclination to learn a system of dance notation as complex as that of Laban, may instead employ some of the terminology and principles of kinesiology. A thorough description of a people's dance would be both more concise and visually explicable when notated by the Laban system. However, because of the complexity of Labanotation (and the consequent difficulty in learning to write or merely to read back the symbols), it might be more expedient for those studying body motion in various cultures to look at such movement with the movement terminology of the kinesiologists. Labanotation seems to be meeting the recording and teaching needs of the dance choreographers. This is not true for researchers of human


27Berofsky, p. 234.
movement in other fields. When Fee's notation system is completed, it may become the answer to the common call for a universal movement notation. One such call was sounded at a recent conference of sport and culture in Brussels.

The fact that no universal system of motor notation has yet been evolved greatly retards the establishment of sport and physical education as a cultural force. In the absence of such a system it is impossible to develop tradition, to formulate concise aesthetic criteria, to rely upon a sufficiently wide range of didactic variants and to engender a sense of historical continuity... To work out a universal system of motor notation represents, I think, the most important single challenge to the science of sport and physical education in our time.28

With the established task of analyzing the spatial aspects of improvisational movement present in this investigation, it is apparent that no system of notation which has been described is relevant to the present methodology and analysis. Notation systems are particularly applicable and lend themselves to: 1) reconstructing movement compositions; 2) recording movement sequences so that they can be repeated both for educational and performing purposes; 3) assisting in the development of accurate and clear movement; and 4) training the power of acute movement observation through notation. None of these is the purpose of this study, nor would any notation system efficiently and expediently assist in the analysis of space utilization.

Literature Related to Qualitative Methods of Movement Analysis

Laban appended his basic notation system to include the analysis of movement quality. He devised graphic representations of movement dynamics in terms of time, space, and force in his system called "effort notation," which concentrates on the manner in which a motion is performed. Behind each motion lies the inner originating impulse to which is given the name "effort." Every action originates in some effort made by the individual, and creates some mood. Similar gestures and movements performed by two people of widely different temperaments will have different expressions because the inner motivations behind the gestures are different. Effort notation does not have the purpose of conveying the motivation behind the movement, the intellectual idea, or the emotional source. Such descriptions are typically conveyed more satisfactorily through words.

But what effort notation does emphasize is the area of dynamics. In describing movement in terms of effort, the parts of the body that move and the direction and level of the movement are relatively unimportant. Effort is analyzed in the following terms: space, time, weight, and flow (control). Space can be direct (straight path) or flexible (curved path). Time can be quick (sudden) or sustained (slow). Weight which is force and strength can be strong or light. Flow (the control of the movement) can be free or bound.

---


Laban's effort model, as presented in Figure 7, displays eight basic effort patterns or combinations of one element each from space, weight, and time; and each combination can be made using free flow or bound flow. Effort observation and notation can be used completely separately from movement notation, or the two can be combined.

The possibility of applying Laban's effort notation system has received serious consideration by investigators. Recently it has been used as an effective tool in observing and analyzing human movement. Hunt revised and expanded Laban's effort model in developing a seven point "movement observation scale" to analyze the amount of effort in terms of force, space, and time for body parts as well as locomotion. Each of the following aspects of the shape in space is also rated on a seven point continuum: path (locomotion, body shape, body parts); and direction (locomotion, body parts). Basic effort patterns and flow patterns receive observation ratings in her schema. This reliable and objective instrument has been satisfactorily used for observations of both unstructured and structured movement patterns.

Using Hunt's observation techniques and scales, Sherman concluded that there is a consistency in the movement patterns of running, kicking, throwing, and skipping in terms of the subject's use of the amount


32 Valerie V. Hunt, "Human Movement," (unpublished material presented in Graduate Seminar, University of California, Los Angeles, Fall Term, 1964).
Figure 7. Laban's Effort Model[^33][^34]

[^33]: Laban, *The Mastery of Movement*, pp. 76-82.

of space, time and force. The lack of individual testing of the subjects in the research methodology suggests that the conclusions may not be warranted due to the compounding effects present. Reliability ratings of the two judges using the movement observation scales were questionably low, ranging from .47 to .48—another reason for skepticism.

In another investigation using Hunt's observation scales, Norman found the instrument to be highly reliable and objective when assessing the ranges of movement on spatial continua for nine and ten year olds.

Frederick and Wilson have recently developed another method to analyze the qualitative aspects of movement and to graphically display movement quality, called "Web Graphics." Laban's concept of effort was incorporated into their model as one of five primary sources of qualitative data. The model display form, called the Web, utilizes five movement components labeled "Effort," "Force," "Balance," "Flexibility," and "Swing." Each component consists of a continuum with rating values from zero to seven. A movement selected for study is given a rating on each of the five component branches. Beneath

---


the Web display of values is a linear graph where the mean value of the combined five component scores is displayed as an indication of the complexity of the movement task under study. The model appears to be less complex than Laban's effort notation, thus resulting in a more easily understood and applied system. Demanding and discriminating thinking is necessary when using this rating system which was designed to improve the subjective judgements one is called upon to make about motor performance. The analysis of this system incorporates as much objectivity as possible.

The validity of applying Laban's effort model to the analysis of movement using Hunt's quantifiable rating form is evident for particular purposes, as is the "Web Graphics" approach. Laban's effort model and Hunt's observation scales are most applicable for the analysis of a single movement or motor skill, or for the determination of a range on the characteristics of movement for any given movement sequence or series of movements. Frederick and Wilson's method for the analysis of movement is recommended for individual movements or motor skills (such as the arabesque, handspring, triple axle, etc.), but the system is inappropriate for the analysis of continuous movement which was the kind elicited by the Movement Task in this investigation. Continuity of the performance would be lost if only particular movements were isolated for analysis. Because this study is concerned with the analysis of these very dimensions of spatial movement, neither Laban's effort model nor Hunt's revision of it could be employed in the present study.
Measurement Techniques Used in Analyzing Spatial Aspects of Human Movement

Interest in early childhood behavior as manifested in play activity has received attention by researchers studying children's use of space. As early as 1930, Barker devised a technique for studying early socialization. Observers drew the path of a subject including only locomotor movements on a scaled floor plan during five-minute intervals. Individual differences were analyzed in terms of gross distance covered, number of activities engaged in, the distribution of time among the activities, the number of social contacts and the average number of activities per unit of time. Similar techniques for charting movement patterns were employed by Dow and Hutt, et al. Dow charted his subjects' movements in a study of the reactions of children to the presence or absence of playground equipment. On scaled plans of the playground areas utilized, the observer charted the path of a subject from point to point for one-minute intervals. The observer also recorded a descriptive account of all the activities engaged in by the subject. Hutt first tape recorded descriptions of children's changes in position with reference to permanent tile squares on a playroom floor. The movements were then plotted on a numbered


representation of the floor space by drawing arrows between the appropriate squares. A description was also transcribed of the child's activity.

With the purpose of minimizing the human error present when using the charting technique, more sophisticated techniques were developed. Swinton first used time-lapse photography to record the movement of several subjects simultaneously. A camera was mounted on the roof of a building overlooking a playground area. The activity of a group of five year old children was filmed for a total of one hour using two-second intervals between pictures. Each one-minute of the movement paths of the children was traced onto pictures of the playground site. Variables analyzed included: interest value of equipment; the amount and character of physical activity; and social behavior.

A unique device was invented by Ellis and Pryer to study gross bodily activity (distance moved) of children with neuropathological problems. An eight foot by eight foot activity room was designed with beams of light arranged in cartesian coordinate fashion at two-foot intervals. The beams of light were focused on photoelectric cells on the opposite side of the room. When a child's movement broke a light beam, then an impulse was registered on a counter. The

---


score of each of six counters was recorded at five-minute intervals.

Scientific-technological advances mushroomed in the 1960's thus providing more advanced techniques for both data collection and data reduction. Herron and Frobish developed a computer analysis and display procedure for reducing cartesian coordinate position data to numerical and graphical statements about movement patterns. 43 A time-lapse photographic system was used to obtain the position data for pre-school children at ten-second intervals throughout a series of fifteen-minute play sessions. Each child's coordinates were identified in each picture by means of a grid taped onto the playroom floor. A computerized display of each child's movement pattern resulted by connecting the cartesian coordinates of the ten-second intervals with straight lines. Wuellner, et al. attempted to improve upon the Herron-Frobish method of data collection and computer analysis and assessed the consistency of pre-school age children's play patterns. 44 A 35mm camera with fisheye lens was mounted on the ceiling of a playroom. Pictures were taken at ten-second intervals during the fifteen-minute play sessions. Both the camera and the one-yard square grid markings on the floor were visible to the three and four year olds. Each child's approximate center of gravity was used in plotting his position


using 0.2 yard intervals. A total of nine play sessions was filmed. Variables analyzed by age, sex, and session included: average distance of each child from all other children; average distance moved by each child; play area locations at the end of each ten-second interval; frequency that each child was alone in each of the play areas; and frequency of entry into each specified play area. The observer reliability was very high for transcribing the cartesian coordinates; however, no substantial analysis was conducted on the length of time for the intervals between pictures. This is an essential step in determining the validity of data sampled as well as in assessing any data distortion present that may result from the ten-second sampling.

A semi-automatic method for reading position data after it had been recorded on film was devised by Haith. A wire grid stood in front of a screen onto which the film had been projected. A scorer touched a metal probe to the vertical and horizontal wires nearest the points on the projected image he wished to measure, and the coordinates of the points were automatically punched on IBM cards. This method appeared to be both expensive and difficult for adaptation to distance photography beyond a few feet, which was necessary in this study.

Video-tape was used by Ahrens to capture two-dimensional expressive movement in an effort to analyze selected spatial dimensions.\footnote{Ahrens, Shirley J., "Spatial Dimensions of Movement," (unpublished Master's Thesis, University of California, Los Angeles, 1966).} McVicker later replicated the methodology in her study investigating additional parameters.\footnote{Carol McVicker, "The Relationship of Self Concept to Use of Space Through Locomotion," (unpublished Master's Thesis, University of Washington, 1971).} However, McVicker's pilot study did not verify subsequent decisions in the choice of spatial measures used for analysis. Another compounding effect that negates most of the conclusions of her study is incorrect conclusions drawn from the comparative analysis with Ahrens' Criterion Study.

A recent study by Mulhauser\footnote{Frederick A, Mulhauser, "An Exploratory Study of Relationships of Space Utilization with Selected Dimensions of Behavior in Children Age Five," (unpublished Doctoral Dissertation, University of Michigan, 1970).} resembles an earlier study by Swinton\footnote{Swinton, "Analysis of Child Behavior," pp. 292-293.} also completed at the University of Michigan. Mulhauser investigated the relationship of four dimensions of space utilization in the horizontal plane with six other variables. When he concluded that five-year-old subjects showed consistency in "total distance traveled," he found that this measure did not necessarily differentiate the use of large amounts of space. Therefore, the only other measure that he analyzed was chosen as indicative of space utilization, an erroneous conclusion. He termed this measure, "area of space used in square feet."

\footnote{Swinton, "Analysis of Child Behavior," pp. 292-293.}
Snyder undertook a study relating selected measures of space utilization to a pre-school inventory predicting school success. Emphasis of the study was upon analyzing social behavior with a structured improvisational play setting. Spatial measures used to analyze the movement of pre-schooler's were borrowed from previous researchers.

It is evident from the limited amount and nature of the descriptive type of research available on the spatial dimensions of movement that there still remains a need for further investigation in this area. In the studies reviewed, only one camera was used to record the data, and therefore, detailed analysis was restricted to a single plane of motion. The Snyder study was an exception to this methodology; but at best, it was an inaccurate attempt to assess linear distance and level change. The overhead camera was positioned at an oblique angle above the play area and two additional cameras were positioned on the floor level. None of the cameras was orthogonally positioned to any other camera. No attempts were made to correct for lens parallax or depth perspective, both of which greatly affect distance computations.

**Human Movement Data Reduction Methods Using Computer Systems**

Technological advances in computer science have provided useful means of data reduction with a minimum of time. Digital computer programs have been written to calculate such data as location of

---

segmental and total body accelerations, joint forces, and other parameters of interest to biomechanics and kinesiology researchers.

Plagenhoef has developed two programs to aid in the complex analysis of total body motion. The first program generates angular velocities and accelerations of segmental displacements, while the second program determines joint forces, moments of force, total body centers of gravity and the contribution of each body segment to the whole motion. Similarly, Garrett, et al., have written a program which computes the center of gravity of the body in two planes and computes a variety of motion characteristics in relation to the displacement of the center of gravity. While planar analysis of joint angles in the Hoffman and Worsham computer technique determines inclinations of the trunk, thigh, leg and foot, the authors have inappropriately applied this method to the analysis of three-dimensional jumping motion without regard for depth coordinate correction. A similar application error has been committed by Baumgartner when using his

---


plot program for the kinesiologic analysis of single camera cinemato-
graphic data. The program yields such results as: 1) a plot of the
path of the theoretical center of gravity for the total action studied;
2) computations of the velocities of particular body parameters;
3) a plot of the path of actions of the two wrists, knees, ankles; and
4) a displacement plot of the center of gravity of the head.

Appropriately regarding the movements under study as three-
dimensional, Miller and Anderson have advanced computer programs
to process kinematic data generating trunk angles, velocity of mass
centers, total angular momentum, and arm movement parameters.

In reviewing these studies of human movement data reduction
methods using digital computer programs, it is evident that none of
them is directly applicable to the present investigation. The input
data for these programs consists of the spatial-temporal coordinates
of bodily points located from the analysis of two-dimensional or three-
dimensional movement. More importantly, the programs are written
to yield specific parameters of interest in a kinesiologic analysis.

54Ted Baumgartner, "Introduction to the Using of the Computer
and the Computer Program Motion," in Selected Topics in Biomechanics,
ed. by J. Cooper. (Chicago: The Athletic Institute, 1971), pp. 51-
58. Proceedings of the C.I.G. Symposium on Biomechanics, Indiana
University, 1970.

55Doris I. Miller, "A Computer Simulation Model of the Airborne
State University, 1970).

56Cynthia C. Anderson, "A Method of Data Collection and Process-
ing for Cinematographic Analysis of Human Movement in Three Dimen-
sions," (unpublished Master's Thesis, University of Wisconsin,
It must be pointed out that results generated by computer reduction methods are only as accurate as the data input. Erroneous conclusions have typically been the result of inappropriate analytic methods considering three-dimensional movement as being only two-dimensional, rather than the result of the data reduction models themselves.

Such is certainly the case with the computer programs applied to the data in the previously reviewed studies that specifically analyzed spatial aspects of movement.\(^57,58,59,60,61,62\) Because of the need to advance a more accurate methodological approach in locating three-dimensional space coordinates coupled with the need to advance new quantifiable dimensions of space utilization, the present study was undertaken.


\(^{58}\)Herron and Frobish, "Computer Analysis and Display of Movement Patterns," pp. 40-44.

\(^{59}\)Ahrens, "Spatial Dimensions of Movement."

\(^{60}\)McVicker, "The Relationship of Self Concept."

\(^{61}\)Mulhauser, "An Exploratory Study of Relationships of Space Utilization."

\(^{62}\)Snyder, "The Relationships Among Various Aspects of Space Utilization."
Photographic Methods of Recording and Analyzing Human Movement

Literature Related to Single Camera Cinematography

Attempts to maintain simplicity of analysis have led to the practice of considering three-dimensional movement as being two-dimensional. Any single camera technique is a two-dimensional representation even though the object photographed is three-dimensional. The perspective of a single camera records objects that possess actual contour and depth but flattens them in the process and projects them onto a two-dimensional plane. Only two of the three spatial coordinates can be measured directly from any single photographic record. This type of analysis is called planar or two-dimensional analysis.

In addition to the studies mentioned assessing space utilization, a single camera and planar analysis have been used in studying three-dimensional skills such as running, jumping, throwing, bowling, and diving.\(^\text{63,64,65,66,67}\) In planar analysis, the movement is usually


filmed in a plane at right angles to the optical axis of the camera. Only the vertical and horizontal displacement of the body can be measured adequately from this record. If lateral movements of the body occur, this movement could not be measured directly from the film.

The single camera stroboscopic techniques producing an overlapping image when a large number of pictures per second are taken has been advocated by Plagenhoef to gather anatomical data for computing joint forces and moments of force on small, rapid movements controllable in a laboratory. 68

Attempts have been made to approximate perspective errors for three-dimensional movement from a single camera. Plagenhoef established an imprecise scale of corrections for non-planar segment angle changes. 69 Doolittle has advocated a method to determine the magnitude of perspective errors and a mathematical technique for their correction regardless of the distance from the camera to the plane of action or the distance of the reference grid from the plane of action. 70 The basic assumption that three-dimensional movement will


be executed in a constant plane and, therefore, can be analyzed on a
two dimension film is erroneous.

The human body has many physical properties peculiar to it, the
most obvious of which is that it represents a three-dimensional form
in space. Because of this property, most bodily movements do not
occur entirely in the two-dimensional film plane, and thus necessitate
human movement analysis to be done in three dimensions. Most three-
dimensional movement requires a more complex technique for analysis
than does some two-dimensional analysis. An infrequently used and
somewhat more complex method of obtaining three-dimensional data from
a single film using only one camera is a mirror technique developed
by Bernstein. By placing a large plane mirror at a $45^\circ$ to the
optical axis of the camera, the resulting photograph records two
images on a single frame. This procedure is equivalent to having
photographed the subject with two perfectly synchronized cameras
placed at right angles to one another. Bernstein then developed
formulae for determining the three spatial coordinates of the selected
movement in the film. However, this required that the points of
interest be visible from both the real and the mirror views of the
subject being photographed. Use of a single camera can, thus, serve
either as the basis for two-dimensional analysis of skills for which
action occurs primarily in one plane or as a basis for limited

---

three-dimensional analysis where prior provision has been made to measure the out of plane movement by indirect means.

Literature Related to Stereophotogrammetry

Human motion in three dimensions has been investigated utilizing principles and methodology of stereophotogrammetry. Stereophotogrammetry is defined as "the science, art and technology of obtaining reliable qualitative information using stereoscopic photography equipment and methods."22 Stereophotogrammetry is based on the same principles as those of binocular vision; an object is photographed by two different cameras placed side by side with the optical axes of the cameras parallel and perpendicular to their focal planes. Each camera records a slightly different image of the object, and the two camera views constitute a stereopair when they are oriented under a suitable optical device so that the right eye sees the right camera photograph and the left eye sees the left camera photograph in proper relationship. As proposed by Hallert, the stereopair can then be used to determine the space coordinates for any point appearing in both photographs.73 Applications of the stereometric measuring technique

---


have been used with acceptable standards of accuracy in biomechanics and human performance studies by Ayoub, et al.\textsuperscript{74} and Gutewort.\textsuperscript{75}

Although stereophotogrammetry has a unique potential for measuring three-dimensional human movement with a high degree of precision, it has remained largely unexploited due to the contributing factors of 1) the expensive equipment necessary and 2) the shortage of photogrammetric engineering services available. The technique would undoubtedly be useful in human movement research where kinetic parameters and functions of rapid motion are of interest such as in the fields of biomechanics and kinesiology, or in the field of anthropometry where still photography is an adequate tool to measure surface area, body contours, and body volume. Stereophotogrammetry was dismissed as an expensive, inapplicable technique for the present study measuring dynamic improvisational movement.

**Literature Related to Multiple Camera Cinematography**

When three-dimensional motion analysis is the major objective, multiple camera methods are recognized as being far superior to existing single camera techniques. Using more than one camera to photograph the performance of a given movement has advantages over the use of a single camera from both a descriptive and an analytic point of


view. Even if no measurements were to be made from the film, an observer studying the side, overhead, and rear or front view of the given movement should gain more information and greater perspective of the movement than if the performance were to be observed only from the traditional side view.

If quantitative information regarding three-dimensional human movement is desired, techniques of planar or two-dimensional analysis can be extended and supplemented to accomplish the objective. Since only two of the three spatial coordinates can be measured directly from any single camera view, it is necessary to obtain the third coordinate from a second camera view synchronized with the first view but photographed from a different angle. This requirement that is basic to the quantitative analysis of three-dimensional movement deserves to be repeated as follows: to measure the spatial coordinates of body parts, the body reference points of interest must be recorded simultaneously by at least two appropriately positioned cameras. The number and placement of cameras for three-dimensional analysis may vary depending upon the movements to be analyzed and the filming facility available. If an overhead filming location is acceptable, cameras placed to photograph the top view, side view, and rear or front view of the performer could maximize the recording of body reference points in at least two of these views simultaneously.
An alternative proposal by Miller suggests the placement of three cameras on ground level separated by angles of 120°.\textsuperscript{76} Precise depth correction can be calculated by the recommended method of using the focal length of the camera lenses, provided the lens-to-object distance is constant. This prerequisite of known camera to subject distance necessary for Miller's method of calculations is non-operative in the present study. This particular method of locating spatial coordinates is inapplicable where the improvisational movements may occur anywhere within the 22 foot by 28 foot rectangular area. More importantly, the suggested camera positioning would preclude obtaining the necessary aerial view of the floor.

Other researchers have used more than one camera to determine accurate spatial coordinates. Realizing that accurate angular measurements were impossible from a single camera, Noss devised a method of finding the "true angle" by averaging the three angle values taken from three cameras positioned along the conventional X, Y, Z axes.\textsuperscript{77} This method is limited to static measures, as is a similar technique proposed by Noble and Kelley.\textsuperscript{78} They used three orthogonally

\textsuperscript{76} Miller, "Three Dimensional Cinematography," p. 33.


positioned cameras to obtain a vertical, a horizontal, and a depth coordinate from each of the three films, resulting in two x, two y, and two z coordinates for each of the fifteen points visible in the corresponding frames of all three cameras. The mean of the two sets of coordinates for each point was taken as the "true" spatial location.

In studying the overarm throw at the University of Wisconsin, both Atwater\textsuperscript{79} and Anderson\textsuperscript{80} located one camera along each of the three coordinate axes. Spatial coordinates along the conventional X,Y,Z axes were determined from two of the cameras, while the third was used to calculate appropriate conversion factors in order to correct for perspective error.

None of the studies cited using multiple camera techniques investigated gross movement patterns which necessitated complex continuous conversion factors, though all of the studies that were reviewed did examine three-dimensional motor skill patterns in confined spaces.

Even though early researchers in physical education using photographic and cinematographic methods have long advocated sound principles for data collection, only with the use of scientific and technological techniques in the studies cited, have there been recent


\textsuperscript{80}Anderson, "A Method of Data Collection and Processing."
attempts to solve the complexities inherent in three-dimensional movement analysis. Additional publications have reiterated common errors of the researcher using photographic techniques.

Reviewing these publications and the experimental methodologies used in the studies which were reviewed, cautionary conclusions regarding data collection using three-dimensional analysis may be summarized as follows:

1. Provision should be made for the calculation of continuous conversion factors for each camera view so that depth correction of the x,y,z spatial coordinates can be accomplished.

---


2. It is necessary to use either a second or third camera view in order to establish precise depth correction.

3. The cameras must be calibrated in terms of frame rate; any variance in asynchronous camera speeds must be corrected prior to the determination of x, y, z data.

4. Provision must be made for synchronizing the x, y, z data on a continuous time base.

Typical techniques used for recording time and synchronizing this time with the movement recorded on one or more films have included either using internal timing lights or including some accurate timing device in the photographic field.

A technique has been developed at Indiana University to solve the problem of the possibility of the timing device, a clock, obscuring a body part of the performer during action, or vice versa if the performer is between the camera and the clock. A beam splitter was used to superimpose the clock over the experimental grid being photographed.

Care must be taken to insure proper maintenance and functioning of any timing light built into the camera mechanism. Such devices typically used in stroboscopic techniques for recording time are very complex and consequently not commonly used. Walton has devised an electronic timing device using neon bulbs calibrated to 1/1000 second.

---

87Ibid.
for use with high speed cameras where both stroboscopic techniques or
the use of a clock placed in view of the camera are inadequate for
accurate synchronization.88

Jonsson, et al, have devised a synchronization method where every
exposure in the film camera (the opening and closing of the camera
shutter) was transmitted by an electrical impulse and marked on an EMG
record.89 The precision of utilizing an electrical impulse to mark
the film may be diminished by irregular feeding of the film and by
the time-consuming process of locating progressive points in time.

A flat-surfaced clock large enough to be visible by the camera
may be appropriate for a single camera view, but a conical timing
device similar to the one invented by Blievernicht is essential when
using two or three cameras.90 It is more applicable with cinematography
when a motion picture analyzer is employed for individual frame
analysis, than with video-tape analysis when it is essential for
continuous play of the video-tape to provide the best clarity. Reading
of the timing device would be less accurate from video-tape analysis
than an audio counting device recorded on a channel parallel to
the movement within the same video-tape recorder.


Summary

This survey has attempted to link the objectives of the present study to the general area of analyzing human movement in relation to non-electronic and photographic methods of recording, and to techniques for measuring spatial aspects in particular. The use of computer systems as a data reduction technique in analyzing movement has been explored.
CHAPTER III

DEVELOPMENT OF THE ANALYTIC METHOD AND VALIDATION PROCEDURES

Theory of Spatial Coordinates

The geometrical problems associated with the proposed two camera method of determining spatial coordinates are of a complex three-dimensional nature. Figure 8 illustrates the positioning of the two cameras. The geometric relationships involving similar right triangles which formed the basis of calculating the y (vertical) and z (depth) coordinates are shown in Figure 9.

Based on Figure 9, a specific illustration is given to demonstrate the mathematical logic used in deriving the general equations for the "true" spatial coordinates Y and Z correcting for perspective error.

Subject front-to-back appears to be at +11 feet from center or 23.25 feet from the backdrop. Subject height appears to be at +3 feet above camera lens height, or 7.17 feet from the floor level. The subject's head appears at +11 feet but is actually less than +11 feet, because the overhead camera at 35.67 feet away distorts outwardly the apparent head location.

Similar right triangles ABC and EDC have equal angles. Distance AB and BC are known, and therefore AC is known. Assume ED = Y. Angle C is common to both triangles. Distance DC must be found so that it can be subtracted from BC, thereby obtaining actual front-to-back (depth) location.
Vertical Distance  A to B = 35.75'
Horizontal Distance  B to C = 73.25'
Camera Height  C to D = 4.17'
Distance of Backdrop
From Back
Boundary Line  E to F = 1.25'
A. Overhead Camera  
B. Center of Front-to-back Test Area  
C. Apparent Head Locus  
D. Actual Head Locus  
E. Subject's Head  
F. Floor Camera  
G. Apparent Height  
H. Sighting Point for Floor Camera  
I. Actual Height  
J. Intersection of Backdrop and Floor  
K. Back Boundary of Test Area  

Figure 9. Side view of performer illustrating distortion from camera lenses.
Tan Angle C = $\frac{AB}{BC}$ and, therefore,

\[ BC = \frac{AB}{\text{Tan Angle C}}. \]

Based on similar triangles, Tan Angle C = $\frac{Y}{DC}$. Transposing and substituting,

\[ DC = \frac{Y}{\text{Tan Angle C}} \quad \text{and} \quad DC = \frac{Y}{AB/BC}. \]

Therefore, actual front-to-back from backdrop equals apparent front-to-back (BC) less the distortion (DC), plus the distance from the center to the backdrop.

\[ Z = BC - \frac{Y}{AB/BC} + 12.25'. \]

Y is unknown. Only the apparent height, Y', is known as the camera height (4.17 feet) plus 3 feet.

Using the same logic as above with symbols E,F,G,H,I, the known triangle base is FH and GH is also known. Therefore,

\[ \text{Tan Angle G} = \frac{FH}{GH} \quad \text{and} \quad GH = \frac{FH}{\text{Tan Angle G}}. \]

Distance GI must be found. Distance EI is Z, and therefore,

\[ GI = \frac{Z}{\text{Tan Angle G}}. \]

Therefore, actual height (Y) equals camera height plus the apparent height (GH) less distortion (GI), or

\[ Y = 4.17' + GH - GI. \]

Since

\[ GI = \frac{Z}{FH/GH}, \]

then

\[ Y = 4.17' + GH - \frac{Z}{FH/GH}. \]
Two equations have been derived in each other's terms:

I. \( Z = 12.25' + BC - \frac{Y}{AB/BC} \)

II. \( Y = 4.17' + GH - \frac{Z}{FH/GH} \)

Substituting known quantities from this example:

I. \( Z = 12.25' + BC - \frac{Y}{35.67/BC} \)

II. \( Y = 4.17' + GH - \frac{Z}{85.67/GH} \)

Proceeding to solve the simultaneous equations, \( Z \) is solved for

in Equation I.

I. \( Z = 12.25' + BC - \frac{Y}{35.67/BC} \)

\[
Z = 12.25' + BC - \left[ \frac{4.17' + GH - \frac{Z}{85.67/GH}}{35.67/BC} \right]
\]

\[
\frac{35.67}{BC} Z = \frac{35.67}{BC} (12.25' + BC) - 4.17 - GH + \frac{Z}{85.67/GH}
\]

\[
\left( \frac{35.67}{BC} \right) Z - Z \left( \frac{GH}{85.67} \right) = \frac{35.67 (12.25' + BC)}{BC} - 4.17 - GH
\]

\[
Z \left( \frac{35.67}{BC} - \frac{GH}{85.67} \right) = \frac{35.67 (12.25' + BC)}{BC} - 4.17 - GH
\]

\[
Z = \frac{35.67 (12.25' + BC) - 4.17 - GH}{35.67/BC - GH/85.67}
\]

\[
Z = \frac{(35.67)(12.25' + BC)(85.67) - 85.67(GH + 4.17)BC}{35.67(85.67) = BC(GH)}
\]
Substituting the original Z value from Equation I into Equation II, Y can be solved.

\[
Y = 4.17 + GH - \frac{Z}{\text{GH}}
\]

\[
Y = 4.17 + GH - \left[ \frac{12.25 + BC}{\text{GH}} \right]
\]

\[
\left( \frac{85.67}{\text{GH}} \right) Y = \left( \frac{4.17 + GH}{\text{GH}} \right) (85.67) - 12.25 - BC + \frac{Y}{35.67/\text{GH}}
\]

\[
Y = \left( \frac{85.67}{\text{GH}} \right) (4.17 + \text{GH}) - 12.25 - BC
\]

\[
Y = \frac{85.67(4.17 + \text{GH})}{\text{GH}} - 12.25 - BC
\]

\[
Y = \frac{85.67(4.17 + \text{GH})35.67 - 35.67\text{GH}(12.25 + BC)}{35.67(85.67) - \text{BC}(\text{GH})}
\]

\[
Y = \frac{(4.17 + \text{GH}) - \text{GH}(12.25 + BC)/85.67}{1 - \text{BC}/35.67 \ast \text{GH}/85.67}
\]

The results are the actual depth coordinate on the Z axis and the actual height coordinate on the Y axis. Generalizing from this example, the actual spatial coordinates (Y and Z) may be calculated from the following formulae given the camera distances from the Movement Task floor area and given the apparent height (y) and the apparent head locus depth (z) of the subject obtained from the synchronized video-tapes:

\*In this and subsequent equations, FORTRAN notation is frequently employed; * denotes multiplication / division. The normal FORTRAN hierarchy of operations is observed. An effort is also made to utilize symbols consistent with those in the computer program contained in Appendix F.
III. Actual Height = Apparent Height -

\[ \text{Apparent Depth} \times \left( \frac{\text{Apparent Height}}{85.67} \right) \]
\[ 1 - \frac{\text{Apparent Depth}}{35.67} \times \frac{\text{Apparent Height}}{85.67} \]

IV. Actual Depth = Apparent Depth -

\[ \text{Apparent Height} \times \left( \frac{\text{Apparent Depth}}{35.67} \right) \]
\[ 1 - \frac{\text{Apparent Depth}}{35.67} \times \frac{\text{Apparent Height}}{85.67} \]

Generalizing the formulae by substituting the cartesian coordinates obtained from the video-tapes, the results are:

V. \[ Y = y - \frac{z \times y/85.67}{1 - (z/35.67 \times y/85.67)} \]

VI. \[ Z = z - \frac{y \times z/35.67}{1 - (z/35.67 \times y/85.67)} \]

Similarly, the actual head locus on the horizontal axis (X) is obtained by deriving an angular shift inward (centerward) from the apparent horizontal location as read from the Overhead camera. This angular shift is a function of (a) the apparent horizontal location, and (b) the apparent height of the subject as read from the floor camera. The formula is:

VII. Actual Horizontal =

\[ \text{Apparent Horizontal} \times (1 - \frac{\text{Apparent Height}}{35.67}). \]

Thus, the further the subject is from the stage center the greater is the inward shift for a given height; and the greater the height, the larger is the inward shift from a given distance from the stage center, and in both instances the amount of shift is related to Overhead camera height which was 35.67 feet.
Generalizing Equation VII by substituting the cartesian coordinates obtained from the video-tapes, the formula becomes:

VIII. \( X = x \times (1 - y/35.67) \)

Validation Procedures

To validate the proposed method, the two television cameras were carefully positioned for the video-taping of the improvisational Movement Task. Analyses of the video-taped views yielded \( x, y, z \) coordinates which were processed by a computer program correcting for camera lens distortion in determining the true \( X, Y, Z \) spatial coordinates. The reliability of the analysis techniques and a comparison of judges' ratings of space utilization with the quantitative measures that were developed to assess space utilization provided a basis for evaluation.

Preparation of the Video-taping Site

The taping was done in the main gymnasium of the Beloit College Fieldhouse on the third weekend of June, 1972. This particular site was chosen because it provided an overhead structure that permitted the mounting of a television camera approximately thirty-six feet above the floor. The site also permitted exclusive use, thus assuring the security and stability of the equipment.

Particular procedures were employed for the video-taping to insure meaningful quantitative analysis. The television cameras were identified as Floor and Overhead. Careful surveying of the gymnasium resulted in the positioning of the two cameras so that their optical
axes intersected and were perpendicular to one another. These conditions, essential to the subsequent calculation of spatial coordinates, were achieved by careful taping of distances and staking of reference points, plumb lines and bob to ensure exact vertical positioning of the instruments, and levels to aid in correct horizontal positioning. The optical axes of the two cameras intersected at the origin of the spatial coordinate system which was arbitrarily set at a height of 4.17 feet above the center of the 22 foot by 28 foot floor area being video-taped. The Floor camera was adjusted to the same height of the origin.

The layout of the taping site is shown in Figure 8 on page 64. The center of the Floor camera lens was located 73.25 feet from the origin while the Overhead camera lens was located 35.67 feet from the gymnasium floor or 31.5 feet above the origin of the spatial coordinate system.

The Floor camera used was an Ampex with a one-inch vidicon tube fitted with a 25mm lens and set at f/1.8. The Overhead camera used was a Sony with a one-inch vidicon tube fitted with a 12.5mm lens and set at f/1.4. The selection of each lens was made with an effort to minimize parallax error and yet provide for the largest possible field of vision given the taping location. The 12.5mm lens of the Overhead camera permitted a field of vision 34.5 feet horizontally and 25.83 feet vertically, while the 25mm lens of the Floor camera televised an area 45 feet by 33.75 feet. Thus, the positioning of the cameras and the specifications of the lenses helped to determine
the dimensions of the floor area to be used for the Movement Task. Twenty-two feet by twenty-eight feet was the size selected for the floor area.

Realizing that the use of video-tape eliminates any errors present in the printing process of cinematographic film as well as errors in film alignment when using an Analyzer or X-Y plotter to analyze cinematographic films, the instrumentation system in this study was markedly different from the instrumentation of studies previously reviewed. Here, the instrumentation system, which is highly sufficient for determining gross changes in movement, consisted of two independent video-tape systems. Each video-tape system consisted of:

1) a fixed camera (specifications previously cited) securely positioned with a calibrated scanning time of thirty pictures/second;
2) a video monitor displaying the simultaneous view from its respective camera (delay was in microseconds); and 3) a video-tape recorder with internal self-correction allowing for the machine to replay a video-tape exactly as it was recorded.

Because it was essential to use a matched camera and video-tape recorder for each individual system, an Ampex VP 4900 video-tape recorder was electronically connected to the Ampex CC 326-10 television camera, while a Sony CV 2000 video-tape recorder was connected to the Sony CV 2300 television camera. The two video monitors in the system were Setchell Carlson models 2100 SD. Both video-tape recorders were electronically connected to each other so that one stop-start switch controlled the action of both recorders. During
the entire taping session, the power of both television cameras remained "on" continually. Even though the motors for the rest of the instruments in the system also were running, it was necessary to record five seconds of video-tape prior to each subject's Movement Task to assure adequate machine warm-up and a consistent rate of operation.

Although the video-tape systems used were highly reliable and precise, it was essential to establish an accurate method of timing so that matched movements from the two different camera views could be identified for the purposes of analyses. An audio counting device was made by tape recording a metronome set at 60 beats/second to which was added a verbal count at one-second frequencies of the cumulative seconds for each minute. At fifteen-second intervals, the minute count preceded the seconds count. The length of the audio counting tape was only ten minutes which necessitated rewinding and replaying the cassette tape for each subject being video-taped, rather than operating it continually. Since identifying individual subjects from the two camera views presented no problem, the ten-minute audio counting tape proved to be more accurate than a longer tape where the accumulated minutes were in two syllable words. The cassette tape of the audio count was electronically connected to the two video-tape recorders so that it was recorded on a channel parallel to the movement within the same video-tape recorder, and thus provided a time calibration standard on each video-tape.
The floor area within which the Movement Task was taped was set apart from the remainder of the gymnasium by the use of eight-foot drapes on two sides and bleachers a few feet away on the third side. The fourth side toward the Floor camera remained unobstructed. The plain drapes provided a contrasting background against which the subject could be seen. The undesired light reflections on the floor were avoided by a heavy tarp covering which was pulled taut and securely fastened. Two-inch wide white tape provided the boundary markings for the 22 foot by 28 foot area. Small pieces of tape were placed upon the tarp in cartesian coordinate fashion at two-foot intervals.

Distance reference scales were established in the Floor camera view by placing a black backdrop 15 inches behind the back boundary line of the testing area. The backdrop was horizontally marked with one-quarter inch white tape at 6-inch intervals from the floor. This rear distance reference scale provided the background grid from which the vertical or y coordinates of movement were obtained during videotape analyses. Similar reference scales with six-inch horizontal markings were video-taped at the intersections of the front and side boundary lines subsequent to the entire video-taping project. By placing the same reference scales at two distinct locations, front and rear of the testing area, provision was made for estimating any lens distortion occurring in the Floor camera. Evaluation showed that no lens distortion existed. The reference scale markings were positioned correctly on the monitor image when compared to the mathematical location of the markings.
Each subject of a known height was video-taped standing against the back reference scale and also against a front reference scale. The distance between the Floor camera and the respective reference scales remained constant throughout the taping project, as did the distance between the Overhead camera and the floor.

Also included in the field of vision adjacent to the testing area and visible from each camera view were large numbers on a contrasting background identifying the subject number and trial number. Swimming lap counters were found to be adequate for these purposes.

A wall clock, heating ventilator, flag, and the floor grid were the stationary objects visible at all times in each camera view and were outlined on the respective monitor screens to subsequently serve as the horizontal and vertical references for the display of video-tapes. Even though the television cameras were securely mounted, it was anticipated that some vibrations could have caused successive portions of the video-tapes to be in slightly different positions. Consequently, to correct for this common error in cinematographic studies, the location of the reference objects during taping was established on the monitor screens with the precaution that the projected images on the respective monitor screens could be adjusted, if necessary, to coincide with the tracings on the monitor surface.

Subjects

The data for this study were obtained from the results of the Movement Task which was administered to twenty-two Beloit College
men and women students ranging in age from eighteen to twenty-three. The volunteer sampling was restricted to students who were enrolled during the Third Term of 1972.

Initial contact with each subject was on an informal basis when the investigator saw him at one of a variety of College campus locations. Each subject was given a brief description of the improvisational Movement Task, and his assistance was requested. No student was told who or how many others had been contacted. Subsequently, an individual appointment for video-taping was arranged with each student, along with directions for wearing appeal. To provide the investigator with additional information, each subject was asked to complete an Activity Background Questionnaire (Refer to Appendix A) following the Movement Task taping. Though analyses in this methodological study did not depend upon the Questionnaire, the results provided additional profile information about the volunteer subjects.

The Questionnaire elicited information regarding a subject's formal instruction and participation in such activities as dance, tumbling, free exercise, baton twirling, judo, karate, wrestling, and stage acting—all thought to be closely related to and influential in performing the Movement Task.

Results of the Questionnaire showed that none of the subjects had had any experience in judo, karate, baton twirling, or stage acting. Participation on a recreational, club, or team basis at the time of the study was non-existent in any of the activities. No compositional or choreographic experience was evident among any of the subjects.
As could have been expected from school physical education curricula, many of the subjects had been exposed to instruction in a variety of the activities. Beginning instruction for a period of time from one month to one year had been received by the following percentages of the subjects in the following activities:

- Folk and Square Dance - 40%
- Social Dance - 10%
- Modern Dance - 50%
- Modern Jazz - 5%
- Wrestling - 5%
- Ballet - 25%
- Gymnastics - 50%

Instruction beyond the fundamental level had been received by only one subject who was exposed to four years of ballet and four years of modern dance.

Past experiences of the subjects, undoubtedly, were reflected in their movements and space utilization. However, the questions of the presence of any past experience effect and the extent of any effect were not within the province of this methodological investigation.

Movement Task

The Movement Task was individually administered to each of the twenty-two subjects. The investigator was the only person present at the time of taping. Subjects had been requested to wear leotards or a minimum of other tight fitting clothing which did not restrict their movements and to appear barefoot. Upon entering the gymnasium, the video-tape instruments were pointed out and briefly explained to the subject. The distance of the video-tape recorders and other
instruments away from the taping area was sufficient to prevent any noise distraction. The subject was then asked to listen to a tape recording giving an explanation of the Movement Task required and the purpose of the study (Refer to Appendix B).

Basically, the subject was asked to "move" freely in any manner he chose within the predetermined floor area. No instruction or suggestion as to possible movements to perform were given to the subject. The unstructured improvisational task was not accompanied by any music, beat, or sound.

Following the instructions, the subject assumed a sitting position in the center of the 22 foot by 28 foot testing area which had been outlined on the gymnasium floor with white tape. Each of the five trials administered to the subjects lasted two and one-half minutes. Time between trials was held constant at one minute.

**General Taping Analysis Techniques**

Simultaneous recordings of a subject by the Floor and Overhead cameras yielded observations of horizontal and vertical displacement of the subject, and depth and horizontal displacement, respectively. To quantify the three-dimensional displacement of the performing subject, data in the form of x, y, z position coordinates were recorded from the two video-tapes. Using the rectangular cartesian coordinate system which had the origin fixed on a non-moving point in the center of the optical field, the location of a point was described by naming its position coordinates along the X, Y, Z axes, as shown in Figure 10. The coordinates on the X and Z axes were located from the
Overhead camera view. From the Floor camera view the $Y$ axis coordinate was obtained.

![Cartesian coordinate system](image)

**Figure 10.** Cartesian coordinate system

The head locus was used in tracking the body position relative to the floor grid squares in order to obtain the $x$ and $z$ coordinates from the Overhead camera video-tape. The $y$ coordinate was determined by locating the highest point of the body in reference to the horizontal scale on the backdrop while viewing the Floor camera video-tape. In reviewing the Overhead view video-tapes, it was concluded that separate tracking of the head from the Floor camera view was unnecessary since the location of the head and the highest body point provided
insubstantial difference. For purposes of distortion elimination from the Overhead view, it was sufficient to track the head locus from the Overhead view and to track the highest body point from the Floor camera.

In the analysis procedures, precise synchronization of the two video-tape views was possible by using the previously described audio timing device which had electronically provided the simultaneous recordings of cumulative time on each of the two video-tapes. Matched portions of the tapes were then able to be analyzed to obtain the x, y, z coordinates.

Due to the poor quality of a short segment of one of the Floor camera tapes, the performance of one subject was not able to be analyzed. This factor diminished the number of subjects in the study to twenty-one.

Each subject was administered 5 two-and-one-half minute trials of the Movement Task. Based upon a previous study by the investigator and its later replication, the first trial was considered a "warm-up" or "familiarizing" trial and thus was not analyzed for any of the subjects. Within the remaining trials 2 through 5, the point estimates of the data which were sampled included the first 30 seconds.

---

2Ahrens, "Spatial Dimensions of Movement," p. 56

middle 30 seconds, and the last 30 seconds of each trial. As a result of the investigator's Pilot Study (See Chapter IV, pp. 93-102) the time interval sampled within the point estimates was set at 4 seconds. Three-dimensional position locations of the necessary body points from the two video-tape views were obtained within this time sampling framework.

Treatment of the Data

Judges' Ratings of the Taped Movement Task. Three well-experienced and highly qualified modern dance instructors evaluated both the Overhead camera and Floor camera views of each subject's performance with the preface that they were to select the three subjects best representative of performers using the most amount of space in all three planes (referred to as the "most expansive" group) and the three subjects best representative of performers using the least amount of space in all three planes (referred to as the "least expansive" group). The judges' impressions of each subject's Movement Task as a whole provided the basis for their selections (Refer to Appendix C). After reading and discussing the guidelines for the video-tape evaluations, the judges were shown a previously taped sample of movement improvisation to illustrate the concepts. Each judge was given a list of subjects in the order to be viewed. To familiarize the judges with the range of subject performances, both views of a subject's performance were simultaneously observed for all subjects before any final selections were made. Each subject's Movement Task was observed a
second time and then judged. Following the day for the selections of
the "most expansive" and "least expansive" group representatives, the
judges subsequently selected three subjects who were representative
of a "medium expansive" group.

The judges' original selections were in complete agreement as to
the three subjects most representative of each of the groups: "least
expansive," "medium expansive," and "most expansive." The judges then
viewed the video-tapes of these nine subjects a fourth time to deter­
mine a rank order within each group.

The three criterion groups based upon the judges' evaluations of
the total Movement Task formed the basis for subsequent validity test­
ing of the three-dimensional analysis methodology proposed for assess­
ing space utilization.

The discriminating power of spatial coordinate change data among
the criterion groups was analyzed by using an analysis of variance
design and t tests. In addition, more rigorous rank order comparisons
were made between the judges' criterion groupings and the six indivi­
dual space utilization measures calculated from the three-dimensional
coordinate values.

Observation provided a direct means of studying the overt gross
motor activity of the subjects. There has been much controversy as to
whether or not observations can be objective. Good and Scates state
that "the fact remains that there are many aspects of behavior which
can be studied satisfactorily in no other way."4 The question of the

4Carter V. Good and D. E. Scates, Methods of Research, Education­
al, Psychological, Sociological, (New York: Appleton-Century-Crofts,
objectivity of one's qualitative assessments warrants examination. It is interesting to note, however, that qualitative evaluations usually emerge from one's opinions, abstractions and impressions. It is exactly this basis that provides for one's hypotheses, subsequently tested through quantitative analysis. This study has been developed from the investigator's original impressions, perceptions, and concepts about movement which are qualitative in nature, and, as such, have provided one of the bases for designing a methodology to quantitatively analyze judges' impressions regarding space utilization.

Pilot Study. A Pilot Study conducted prior to the main analyses determined the optimum time interval for video-tape analysis with a view to eliminate a suspected loss and distortion of data resulting from longer time intervals.

The data of a stratified sample of nine subjects who had been judged as either "most expansive," "medium expansive," or "least expansive" were used. The two video-tape views of the nine subjects were analyzed exactly as previously described in order to obtain the x, y, z position coordinates. The parameter under study, time interval, varied in length and included analyses of the video-tapes at 2, 4, 6, 8, 10, and 15-second intervals. The "percentage loss of data" per group was calculated across the varying interval lengths.

Reliability of Tape Analysis Procedures. An inter-observer reliability coefficient was estimated for each of the three spatial coordinates, x, y, and z, on data from 43 percent of the subjects. The investigator and another observer each independently analyzed
the video-tapes of the sampled subjects to determine the three cartesian coordinates. The two sets of data for each of the cartesian coordinates were subjected to the Pearson-Product Moment correlation method to determine the inter-observer reliability coefficient.

The intra-observer reliability coefficients were estimated by having the investigator analyze the same tapes a second time in an effort to assess the accuracy with which the spatial coordinates were located on the video-tapes. The second analysis was performed six months following the first analysis. Both an analysis of variance method and the Pearson-Product Moment correlation method were used to estimate the intra-observer reliability coefficients on the two independent sets of data for each of the cartesian coordinates.

Data Processing and Calculation of the Spatial Measures. The three-dimensional spatial coordinates obtained from the two camera views for each of the twenty-one subjects comprised the data which were punched on cards and processed on an IBM 1600 digital computer. Input to the computer program (Refer to Appendix F) included the camera origin distances for both cameras. This information, in conjunction with the x-y-z values from the video-tapes, was used to solve the equations for determining the "true" spatial coordinates as explained in Chapter III, pages 63-70.

The true spatial coordinates, X, Y, Z were then used to generate the selected quantitative measures of space utilization. These selected measures consisted of the following:
A. Linear Distance Traveled
B. Level Change
C. Level Range as a Percentage of Subject's Height
D. Percentage of Possible Floor Grid Shifts
E. Percentage of Enterable Grid Squares Entered
F. Floor Pattern Range

Using the corrected X and Z coordinates relative to the two-foot grid squares on the floor, linear distances between the consecutive spatial locations obtained at four-second intervals were computed and summed to provide a trial score. The four trial scores were then summed and averaged to represent the Linear Distance Traveled measure. This measure gave an indication of a subject's mobility.

Level Change may be thought of as the total linear vertical change of the subject's body during any given trial. The level of the body at any measured point in time was taken to be the distance from the floor to the highest body point. Calculations of this measure were made possible by taking the absolute difference between the consecutive Y coordinates throughout a trial and then summing these differences. The Y coordinates were scored in half-foot intervals and obtained at four-second intervals within the trial sampling. The individual trial sums were computed and then summed, and averaged.

Level Range was calculated by finding the difference between the maximum and the minimum levels attained for each trial as evidenced by the Y coordinates. An average of the four trials was computed. These respective linear distances were then converted to a percentage of the subject's height.

The Percentage of Possible Floor Grid Shifts measure was based upon the X and Z coordinates in relation to the floor grid squares.
The measure was calculated as the ratio between the sum of the number of location changes a subject made from one grid square to a different grid square during each trial and the number of possible location changes a subject could have made during a trial based upon the four-second interval sampling. The ratio was then expressed as a percentage for each trial and for the average. This measure also presented some evidence of a subject's mobility.

Percentage of Enterable Grid Squares Entered was the name of the measure given to the ratio between the number of distinct or unique grid squares entered by a subject and the number of possible grid squares available for entry within the time points sampled. The ratios for the individual trials and for the average were then expressed as percentages. Even though a subject entered the same grid square more than once, that distinct grid square was counted as having been entered only once. This particular method of scoring allowed for distinguishing between a subject who entered a great many distinct grid squares and the subject who continually moved in a restricted number of grid squares. The measure was indicative of an "areal" quality present in space utilization.

The final spatial measure employed in analyzing space utilization was called the Floor Pattern Range. Similar to the Level Range measured on the Y axis, the Floor Pattern Range based upon the X and Z coordinates was calculated by finding the greatest difference between any two grid square locations for each trial. An average of the four trials was calculated.
It should be pointed out that the computerized calculations based upon the time point sampling within each trial provided a symptomatic analysis of space utilization. The computer program assumed that all intermediate points between two observed points in time were linearly connected. Only if the interval sampling were to be increased to tenths of a second, would a more definitive analysis of space utilization result when employing the same methodology, data reduction, and data analysis.

Accuracy was a major concern in the development of the computer program. A number of logical checks were included in the methodology to identify the presence of gross errors in the computations. The first step involved setting an upper and lower limit on each of the three spatial coordinate values. These limits defined by the ranges of the vertical grid and the floor grid were incorporated into the computer program as a check against the input of extreme location data.

Secondly, each of the six spatial measures was closely examined relative to its theoretical relationship. Based upon the definition and mathematical relationships of the six spatial measures, the Pilot Study data were closely examined to determine the feasibility of their magnitudes.

Thirdly, hand computations were made from the Pilot Study data and then compared to the computer programmed calculations for the following space utilization measures: Level Change, Level Range, Percentage of Possible Floor Grid Shifts, and Percentage of Enterable Grid Squares Entered. In each case, if errors occurred, the errors
were of a negligible magnitude, and thus, were assumed to be due to rounding.

Reliability of Spatial Measures. The quantification of three-dimensional movement, as previously described, yielded scores on six spatial measures indicative of space utilization. A trend analysis test across the four trials was performed, and the reliability of these newly proposed measures was calculated by means of an analysis of variance technique for estimating intraclass correlation.

Level of Significance. For the purpose of this investigation, a .05 level of significance was selected as a reasonable probability for testing significant differences.
CHAPTER IV
DISCUSSION AND ANALYSIS OF RESULTS

The purpose of this study was to develop and validate a method for measuring the three-dimensional space utilization of unstructured human movement. Two video-tape systems which were electronically parallel were used to record the three-dimensional data elicited by the improvisational Movement Task. Analysis techniques employing mathematical corrections for photographic perspective error were devised and incorporated into a suitable computer program. The proposed method was experimentally evaluated by testing its accuracy and adequacy as an index of space utilization in human movement.

Reliability of Tape Analysis

One of the purposes of this phase of the study was to determine whether two independent observers would consistently identify the positions of a subject using three-dimensional space coordinates. The data from a stratified sampling of nine subjects were analyzed according to the techniques described in Chapter III. Pairing each of the respective x, y, z coordinates reported by each observer, this method yielded Pearson-Product Moment correlations for each of the coordinates. The results, as presented in Table 1, show the extremely high inter-observer reliabilities. The video-tape analysis techniques were sufficiently reliable for two independent observers to extrapolate the three-dimensional space coordinates.
The second purpose of this phase of the study was to determine whether one of the observers would consistently identify the position of a subject using three-dimensional space coordinates if the two independent analyses of the same video-tapes were made at an interval of six months. Using each of the paired scores on the respective spatial coordinates, the intra-observer reliabilities were estimated by an analysis of variance method yielding an intraclass correlation coefficient ($R$) and by the Pearson-Product Moment correlation method. The comparative results of the two methods are presented in Table 2.

**TABLE 1**

A SUMMARY OF INTER-OBSERVER RELIABILITY COEFFICIENTS
(N=9)

<table>
<thead>
<tr>
<th>Spatial Coordinate</th>
<th>$r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal (x)</td>
<td>.98</td>
</tr>
<tr>
<td>Vertical (y)</td>
<td>.96</td>
</tr>
<tr>
<td>Depth (z)</td>
<td>.98</td>
</tr>
</tbody>
</table>

**TABLE 2**

A SUMMARY OF INTRA-OBSERVER RELIABILITY COEFFICIENTS
(N=9)

<table>
<thead>
<tr>
<th>Spatial Coordinate</th>
<th>$R$</th>
<th>$r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal (x)</td>
<td>.999</td>
<td>.998</td>
</tr>
<tr>
<td>Vertical (y)</td>
<td>.986</td>
<td>.973</td>
</tr>
<tr>
<td>Depth (z)</td>
<td>.999</td>
<td>.998</td>
</tr>
</tbody>
</table>
The analysis of variance summaries for each of the spatial coordinate reliability estimates are shown in Tables 3, 4, and 5.

**TABLE 3**  
**SUMMARY OF ANALYSIS OF VARIANCE**  
**FOR THE HORIZONTAL SPATIAL COORDINATE (x)**  
*(N=9)*

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Subjects</td>
<td>200,734.0</td>
<td>8</td>
<td>25,091.75</td>
</tr>
<tr>
<td>Between Trials</td>
<td>168.0</td>
<td>1</td>
<td>168.00</td>
</tr>
<tr>
<td>Error</td>
<td>206.5</td>
<td>8</td>
<td>25.81</td>
</tr>
<tr>
<td>Total</td>
<td>201,108.5</td>
<td>17</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 4**  
**SUMMARY OF ANALYSIS OF VARIANCE**  
**FOR THE VERTICAL SPATIAL COORDINATE (y)**  
*(N=9)*

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Subjects</td>
<td>10,698.62</td>
<td>8</td>
<td>1337.33</td>
</tr>
<tr>
<td>Between Trials</td>
<td>.02</td>
<td>1</td>
<td>.02</td>
</tr>
<tr>
<td>Error</td>
<td>150.10</td>
<td>8</td>
<td>18.76</td>
</tr>
<tr>
<td>Total</td>
<td>10,848.74</td>
<td>17</td>
<td></td>
</tr>
</tbody>
</table>
TABLE 5
SUMMARY OF ANALYSIS OF VARIANCE FOR THE DEPTH SPATIAL COORDINATE (z) (N=9)

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Subjects</td>
<td>73,080.45</td>
<td>8</td>
<td>9135.06</td>
</tr>
<tr>
<td>Between Trials</td>
<td>40.50</td>
<td>1</td>
<td>40.50</td>
</tr>
<tr>
<td>Error</td>
<td>46.00</td>
<td>8</td>
<td>5.75</td>
</tr>
<tr>
<td>Total</td>
<td>73,166.95</td>
<td>17</td>
<td></td>
</tr>
</tbody>
</table>

Based on the data presented in Tables 3, 4, and 5, the intraclass R was estimated by the formula, 

$$R = \frac{MS_S}{MS_S - MS_E}$$

The high intra-observer reliabilities presented in Table 2 confirm the consistency with which the three-dimensional space coordinates were extracted from the video-taped Movement Task.

Hypothesis one stated that a reliable and accurate method for the location of spatial coordinates in three dimensions could be devised. Based upon the previous results of the inter-observer reliabilities and the intra-observer reliabilities, hypothesis one is supported.

Judges' Ratings of the Taped Movement Task

Three dance experts served as judges for the video-tape analysis whereby the three subjects most representative of the following three groups were selected: least expansive, medium expansive, and most
expansive. (Refer to Appendix C) Because the subjects moved characteristically in a consistent way and because there were pronounced differences among the subjects, the judges unanimously agreed in their selections for the composition of each group. There was some variability, however, in the judges' ratings to determine a rank order within each group. The results of the within group rank order ratings are summarized in Table 6. The highest rank was given a

<table>
<thead>
<tr>
<th>Criterion Group</th>
<th>Subject No.</th>
<th>Judges</th>
<th>Rating Total</th>
<th>Average Rating</th>
<th>Final Assigned Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1.00</td>
</tr>
<tr>
<td>Expansive</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2.33</td>
</tr>
<tr>
<td>Medium</td>
<td>20</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>1.33</td>
</tr>
<tr>
<td>Expansive</td>
<td>17</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1.67</td>
</tr>
<tr>
<td>Least</td>
<td>14</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1.00</td>
</tr>
<tr>
<td>Expansive</td>
<td>18</td>
<td>2</td>
<td>2</td>
<td>6</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>3</td>
<td>3</td>
<td>9</td>
<td>3.00</td>
</tr>
</tbody>
</table>

To determine the over-all rank of the subjects within each group, each subject's three ratings were summed and averaged. This average rank was the basis for establishing the order within each group and was subsequently used for a part of the validity testing of the proposed methodology.
To ascertain the over-all agreement among the rankings by the three judges, Kendall's coefficient of concordance (W) was employed. This measure of interjudge reliability was an index of the divergence of the actual agreement (shown in the data in Table 6) from the maximum possible (perfect) agreement. The computed W equalled 9.85 which was significant beyond the .01 level.

**Pilot Study**

Prior to locating the three-dimensional space coordinates of the subjects' positions on the video-tapes from both camera views, it was necessary to determine the optimum time interval for the analysis. The Pilot Study which served that purpose was designed to select the time interval which would minimize the amount of analytic work required in viewing the video-tapes, and still minimize the loss and distortion of data which was suspected to result with increasing time intervals. The stratified sampling of nine subjects (43% of the total group) was used to determine the interval. Based upon previous judges' ratings, these subjects had been categorized into three groups: most expansive, medium expansive, and least expansive.

Spatial coordinates on the X,Y,Z axes were identified from the two camera views for each subject at intervals of 2, 4, 6, 8, 10, and 15 seconds on each of trials two through five. The basis for the subsequent analysis was the determination of a score indicative of change in the separate directions of horizontal (x), vertical (y), and depth (z) by summing the absolute differences between the like coordinates at consecutive points in time within each of the time
intervals sampled. This was done for each of the subjects on each of the four trials. It was then possible to compute a mean of the trials for horizontal change, vertical change, and depth change. These scores of the subjects' movement change in each of the three dimensions were then used to calculate the percentage loss in data between various time intervals sampled.

**Percentage loss in data**

The percentage loss in data measure gave an indication of the amount of data lost by identifying spatial coordinates every 4, 6, 8, 10, or 15 seconds instead of every 2 seconds. The measure was computed by subtracting the smaller score of the two intervals from the larger score, dividing this difference by the larger score, and multiplying the quotient by 100 to obtain the percentage loss in data. For example:

Horizontal change score based on 2-second interval = 38.50
Horizontal change score based on 4-second interval = 25.25

\[
\% \text{ loss} = \frac{38.50 - 25.25}{38.50} \times 100
\]

The percentage loss in this example would be interpreted as the amount of data lost on the horizontal dimension of the subject's movement by identifying the horizontal coordinate on the video-tape every four seconds instead of every two seconds.

It appeared from the summary of percentage loss in data presented in Table 7 that in attempting to minimize the loss in data and minimize the work cost, there was a viable alternative to the two-
<table>
<thead>
<tr>
<th></th>
<th>2-4 sec.</th>
<th>2-6 sec.</th>
<th>2-8 sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Most Expansive</td>
<td>Most Expansive</td>
</tr>
<tr>
<td><strong>Group</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subject 1</td>
<td>3</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Vertical</td>
<td>32.06</td>
<td>19.72</td>
<td>26.88</td>
</tr>
<tr>
<td>Horizontal</td>
<td>22.70</td>
<td>18.28</td>
<td>24.71</td>
</tr>
<tr>
<td>Depth</td>
<td>27.24</td>
<td>28.38</td>
<td>25.00</td>
</tr>
<tr>
<td><strong>Group X</strong></td>
<td></td>
<td>27.33</td>
<td>28.13</td>
</tr>
<tr>
<td><strong>2-4 sec.</strong></td>
<td></td>
<td>24.99%</td>
<td></td>
</tr>
<tr>
<td><strong>Medium Expansive</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subject 2</td>
<td>20</td>
<td>17</td>
<td>5</td>
</tr>
<tr>
<td>Vertical</td>
<td>39.93</td>
<td>34.64</td>
<td>30.21</td>
</tr>
<tr>
<td>Horizontal</td>
<td>24.54</td>
<td>18.73</td>
<td>17.13</td>
</tr>
<tr>
<td>Depth</td>
<td>36.82</td>
<td>11.68</td>
<td>20.77</td>
</tr>
<tr>
<td><strong>Group X</strong></td>
<td>33.76</td>
<td>21.68</td>
<td>22.77</td>
</tr>
<tr>
<td><strong>2-6 sec.</strong></td>
<td>26.05%</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Medium Expansive</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2-8 sec.</strong></td>
<td>28.86%</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Least Expansive</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subject 3</td>
<td>14</td>
<td>18</td>
<td>8</td>
</tr>
<tr>
<td>Vertical</td>
<td>32.43</td>
<td>37.71</td>
<td>31.03</td>
</tr>
<tr>
<td>Horizontal</td>
<td>22.38</td>
<td>29.07</td>
<td>28.33</td>
</tr>
<tr>
<td>Depth</td>
<td>22.66</td>
<td>21.07</td>
<td>35.11</td>
</tr>
<tr>
<td><strong>Group X</strong></td>
<td>25.82</td>
<td>29.28</td>
<td>31.49</td>
</tr>
<tr>
<td><strong>2-8 sec.</strong></td>
<td>40.35%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE 7
HORIZONTAL, AND DEPTH CHANGE DATA ACROSS VARIOUS INTERVALS

<table>
<thead>
<tr>
<th></th>
<th>2-8 sec. Most Expansive</th>
<th></th>
<th>2-10 sec. Most Expansive</th>
<th></th>
<th>2-15 sec. Most Expansive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ct</td>
<td>3</td>
<td>1</td>
<td>9</td>
<td>Subject</td>
</tr>
<tr>
<td>cal</td>
<td></td>
<td>79.15</td>
<td>43.53</td>
<td>47.31</td>
<td>Vertical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>64.17</td>
<td>62.11</td>
<td>60.05</td>
<td>Horizontal</td>
</tr>
<tr>
<td>cal</td>
<td></td>
<td>63.78</td>
<td>66.24</td>
<td>64.75</td>
<td>Depth</td>
</tr>
<tr>
<td>cal</td>
<td></td>
<td>69.03</td>
<td>57.29</td>
<td>57.37</td>
<td>$\bar{X}$</td>
</tr>
<tr>
<td>cal</td>
<td></td>
<td>61.23%</td>
<td>Group $\bar{X}$</td>
<td>58.20%</td>
<td>Group $\bar{X}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>2-8 sec. Medium Expansive</th>
<th></th>
<th>2-10 sec. Medium Expansive</th>
<th></th>
<th>2-15 sec. Medium Expansive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ct</td>
<td>20</td>
<td>17</td>
<td>5</td>
<td>Subject</td>
</tr>
<tr>
<td>cal</td>
<td></td>
<td>62.99</td>
<td>62.13</td>
<td>62.50</td>
<td>Vertical</td>
</tr>
<tr>
<td>cal</td>
<td></td>
<td>54.58</td>
<td>56.18</td>
<td>47.81</td>
<td>Horizontal</td>
</tr>
<tr>
<td>cal</td>
<td></td>
<td>66.36</td>
<td>75.91</td>
<td>35.38</td>
<td>Depth</td>
</tr>
<tr>
<td>cal</td>
<td></td>
<td>61.31</td>
<td>64.74</td>
<td>48.56</td>
<td>$\bar{X}$</td>
</tr>
<tr>
<td>cal</td>
<td></td>
<td>58.20%</td>
<td>Group $\bar{X}$</td>
<td>62.19%</td>
<td>Group $\bar{X}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>2-8 sec. Least Expansive</th>
<th></th>
<th>2-10 sec. Least Expansive</th>
<th></th>
<th>2-15 sec. Least Expansive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ct</td>
<td>14</td>
<td>18</td>
<td>8</td>
<td>Subject</td>
</tr>
<tr>
<td>cal</td>
<td></td>
<td>70.33</td>
<td>58.12</td>
<td>62.77</td>
<td>Vertical</td>
</tr>
<tr>
<td>cal</td>
<td></td>
<td>58.57</td>
<td>56.90</td>
<td>50.00</td>
<td>Horizontal</td>
</tr>
<tr>
<td>cal</td>
<td></td>
<td>57.03</td>
<td>60.19</td>
<td>60.82</td>
<td>Depth</td>
</tr>
<tr>
<td>cal</td>
<td></td>
<td>61.98</td>
<td>58.43</td>
<td>57.86</td>
<td>$\bar{X}$</td>
</tr>
<tr>
<td>cal</td>
<td></td>
<td>59.42%</td>
<td>Group $\bar{X}$</td>
<td>54.53%</td>
<td>Group $\bar{X}$</td>
</tr>
</tbody>
</table>
second interval. If the four-second interval was selected for the data point locations, each of the three criterion groups could be considered as losing about an equal percentage of data from the 2- to the 4-second interval (24.99%, 26.05%, 28.86%). The most important consideration in the selection of the time interval was not the percentage of data lost in successive intervals, but rather the relative percentages of loss among the three groups. Given the latter precaution, the conclusions drawn from the data sampled at 4-second intervals would remain consistent among the groups with the conclusions that would result from the 2-second interval data analysis.

A condensation of the data from Table 7 is presented in Table 8, showing the means and ranges by groups for the percentage loss in combined data for various time intervals. Figure 11 presents a graphical display of the data summarized in Table 8. It is evident that the percentage loss of data from two to four seconds resulted in the three groups being tightly clustered at the 4-second interval, thereby showing virtually parallel slopes in Figure 11 between the 2- and 4-second intervals. These two conditions were only present again at the eight-second interval where the three groups had the least spread. Due to the high percentage loss in data, 58%-61%, the eight-second interval was discarded as a possible choice for the data sampling with the view that more valid conclusions would be drawn from losing only 25% of the data (choosing the 4-second interval) than if approximately 60% of the data were unused (choosing the 8-second interval). From this analysis, therefore, the 4-second
<table>
<thead>
<tr>
<th></th>
<th>2-4 sec.</th>
<th>2-6 sec.</th>
<th>2-8 sec.</th>
<th>2-10 sec.</th>
<th>2-15 sec.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1a</td>
<td>24.99</td>
<td>36.03</td>
<td>61.23</td>
<td>60.77</td>
<td>73.64</td>
</tr>
<tr>
<td></td>
<td>(25.53 - 28.3)</td>
<td>(30.95 - 42.04)</td>
<td>(57.29 - 69.03)</td>
<td>(55.52 - 69.32)</td>
<td>(71.37 - 76.68)</td>
</tr>
<tr>
<td>Group 2b</td>
<td>26.05</td>
<td>36.57</td>
<td>58.20</td>
<td>62.19</td>
<td>71.80</td>
</tr>
<tr>
<td></td>
<td>(21.68 - 33.76)</td>
<td>(32.45 - 38.91)</td>
<td>(48.56 - 64.74)</td>
<td>(52.97 - 68.01)</td>
<td>(67.41 - 77.03)</td>
</tr>
<tr>
<td>Group 3c</td>
<td>28.86</td>
<td>40.35</td>
<td>59.42</td>
<td>54.53</td>
<td>67.49</td>
</tr>
<tr>
<td></td>
<td>(25.82 - 31.49)</td>
<td>(38.21 - 43.99)</td>
<td>(57.86 - 61.98)</td>
<td>(48.11 - 62.28)</td>
<td>(64.33 - 71.51)</td>
</tr>
<tr>
<td>Range X</td>
<td>3.87</td>
<td>4.32</td>
<td>3.03</td>
<td>7.66</td>
<td>6.15</td>
</tr>
</tbody>
</table>

a = Most Expansive Group  
b = Medium Expansive Group  
c = Least Expansive Group
Figure 11. Mean Percentage Loss of Spatial Data for Each Group from 2-4 seconds, 2-6 seconds, 2-8 seconds, 2-10 seconds, and 2-15 seconds.
interval appeared to minimize the loss of data at an equal rate across the groups.

**Rank Order of the Means of Combined Spatial Direction Change**

Although there was a relatively large loss in data from interval to interval, Figure 11 showed the loss was consistent across the groups for 2, 4, 6, and 8-second intervals. Presented in Figure 12 are the rank orders of change in spatial coordinates recorded for each subject at each time interval. The rank orders remained relatively constant from the 2-second interval through the 6-second interval. The rank orders for the subjects at the 4- and 6-second intervals each had one minor shift of a very small magnitude compared to the 2-second interval. Radical shifts in the rank order positions occurred at the 8-, 10-, and 15-second time intervals when several shifts occurred within each rank order. Because of the high consistency of rank orders for the 2-, 4-, and 6-second intervals, there was a tendency for the increasing sample interval to subtract similarly from the change in spatial coordinates for these intervals. The evaluation of the rank orders supported the accuracy in selecting either the 2-, 4-, or 6-second interval. Upon closer scrutiny, it was found that the shift occurring at the 6-second interval (between subjects 1 and 3) was greater in magnitude than the shift occurring at the 4-second interval between subjects 17 and 20. Thus, the 4-second interval was selected in preference to the 6-second interval as being the more viable alternative to the 2-second interval.
Figure 12. Rank Order of the Mean of Combined Vertical, Horizontal, and Depth Changes for Each Subject at Each Interval (Trials 2-5)

(N = 9)
Means of Trials 2-5 of the Combined Spatial Direction Change for Each Subject at Each Time Interval

Figure 13 expressed the mean of the combined vertical, horizontal and depth changes for each subject, trials 2-5, at each time interval. Although the recorded changes on the combined dimensions decreased at successive time intervals for each subject, the greatest loss for all subjects appeared during the increase from 2 to 4 seconds. The individual scores were spread across a broad range until the interval was increased to eight seconds whence the increase lost its discriminating power between subjects. Using discriminating power as a criterion, both the 4 and 6 second intervals appeared to be satisfactory.

Means of Trials 2-5 of the Combined Spatial Direction Change for Each Group at Each Time Interval

The comparison of the criterion group means across varying intervals is displayed in Figure 14. The vertical, horizontal, and depth change scores were summed for each trial and then summed across trials 2-5 for each group. Group averages were then calculated. The findings followed the same general declining trend of data scores as the sampling interval increased over time.

Conclusion

The best sampling interval to maximize accuracy and minimize work cost was 4 seconds. Although some data was lost by increasing the sampling interval from two to four seconds, the loss was consistent across the three criterion groups and did not appreciably disturb
Figure 13. Mean of Combined Vertical, Horizontal, and Depth Change for Each Subject at Each Time Interval (Trials 2-5) (N=9)
Figure 14. Mean of Combined Vertical, Horizontal, and Depth Change for Each Group at Each Time Interval (Trials 2-5)

- ▲ = Most Expansive Group
- ○ = Medium Expansive Group
- ▼ = Least Expansive Group
the ranking of the subjects, nor did the 4-second interval choice inhibit the discrimination among subjects.

**Validation of the Space Utilization Measures**

A method for locating the three-dimensional coordinate values of body positions during the unstructured Movement Task was devised. Quantitative measures to assess space utilization were based upon the three-dimensional coordinate values. Ratings by three independent judges of the subjects' video-taped Movement Tasks also yielded information regarding the subjects' space utilization. The judges' resultant criterion groupings formed the basis for comparison of their ratings and the quantitative measures of space utilization. The measures of space utilization employed were the following:

A. Linear Distance Traveled  
B. Level Change  
C. Level Range as a Percentage of Subject's Height  
D. Percentage of Possible Floor Grid Shifts  
E. Percentage of Enterable Grid Squares Entered  
F. Floor Pattern Range

A complete explanation of and calculating procedures for the space utilization measures were presented in Chapter III. The two measures based solely upon the vertical (Y) spatial coordinates were Level Change and Level Range. The remaining four measures were indicative of position change in the combined horizontal (X) and depth (Z) planes.

Because each of the space utilization measures did not evaluate movement in all three planes and because some measures were best
understood as percentages while others were calculated in linear feet, it was necessary to deal with the data in the form of spatial coordinates. The spatial coordinate values, then, provided the basis for determining whether the vertical, horizontal, and depth changes would in fact discriminate among the least expansive, medium expansive, and the most expansive performers.

For each of the three dimensions involved, horizontal (x), vertical (y), and depth (z), a change score was obtained for each subject for each trial by summing the absolute differences between the like coordinates at consecutive points in time. This resulted in a vertical change score, a horizontal change score, and a depth change score, by trial. The three scores were then weighted as a composite in the following appropriate fashion:

Weighted Composite Change Score =

\[ 0.5 \text{ Vertical Change} + 0.25 \text{ Horizontal Change} + 0.25 \text{ Depth Change} \]

(Refer to Appendix D)

The weighted composite change scores for each trial were summed and averaged.

An explanation of how the weightings were derived is in order. Judges were called upon to give a total impression of the space utilization of each Movement Task from their observation of evidence recorded by the two cameras. From the Floor camera they were to observe vertical movement, and from the Overhead camera they were to observe angular movement on the floor plane. Objective numerical equivalents of these two judgement bases were achieved by assigning equal weight to the evidence from each camera. To achieve this the vertical change score was given a weight of 0.50 as was the angular movement change.
score. But in the latter case the weighting methodology required assigning .25 to the horizontal change score and .25 to the depth change score to reach a total weight of .50 for the composite angular movement.

In determining the discrimination power of the weighted composite change score among the criterion groups, two questions were raised.

1. Does the weighted composite change score discriminate among the general family patterns of the most expansive group, the medium expansive group, and the least expansive group?

2. Can each individual from each family pattern be discriminated from each of the entire other family patterns on the basis of the weighted composite change score? That is, can it be reasonably assumed that each subject is not included in either of the remaining two criterion groups' scores?

To answer the first question, a one-way analysis of variance was employed to determine if the three groups, most expansive, medium expansive, and least expansive, could be significantly distinguished on the basis of the weighted composite change scores. The results presented in Table 9 indicate the obtained F ratio was significant at the .05 level.

The significant F only says that some effects presumably exist; it says nothing about the source of these effects. Typical post-hoc comparisons use a series of t tests in order to test the differences between pairs of means. Because this procedure is less preferable, the investigator selected a more conservative approach, the Schaffé method in order to test the group mean differences without inflating the alpha level.
TABLE 9
SUMMARY OF ANALYSIS OF VARIANCE OF WEIGHTED COMPOSITE CHANGE SCORE (N=9)

<table>
<thead>
<tr>
<th>Source</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1367.27</td>
<td>2</td>
<td>683.64</td>
<td>31.52a</td>
</tr>
<tr>
<td>Within Groups</td>
<td>130.11</td>
<td>6</td>
<td>21.69</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1497.38</td>
<td>8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$^aF_{.05(2, 6)} \geq 5.14$

The differences in group means are summarized in Table 10.

TABLE 10
A SUMMARY OF THE SCHEFFE TEST FOR SIGNIFICANCE OF DIFFERENCES BETWEEN GROUP MEANS FOR WEIGHTED COMPOSITE CHANGE SCORE

<table>
<thead>
<tr>
<th>Medium Expansive</th>
<th>Least Expansive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most Expansive</td>
<td>15.33a</td>
</tr>
<tr>
<td>Medium Expansive</td>
<td>14.86a</td>
</tr>
</tbody>
</table>

$^a$Significant at the .05 level

The Scheffe procedure compares the difference between pairs of sample means with a computed $S$ value. If a difference is greater than the $S$ value, then the two means in question are said to be significantly different from each other at the stated alpha level. The $S$ value was calculated as follows:
\[
S = \left( \frac{F_{.05; r-1; N-r}}{r-1} \right) \left( \frac{MSE}{2/n} \right)
\]

where \( r \) = number of groups, \( F \) = a tabled value, \( .05 \) = the probability of making a Type I error, \( N \) = total number of observations, \( MSE \) = the error mean square term, \( n \) = number of observations within each group.

\[ S = 12.20 \]

Comparing the differences from Table 10 with the \( S \) value, it was concluded that the weighted composite change score discriminated at the \( .05 \) level of significance between each of the group means. Therefore, question 1 regarding the discrimination power of the composite score was answered affirmatively. Likewise, hypothesis two was also given support by the preceding analysis.

The second question posed the ability of the weighted composite change score to discriminate each subject in each criterion group from each of the other criterion groups. The series of \( t \) test comparisons are presented in Table 11. When calculating the \( t \) ratio, the subject's individual mean score and the comparative group standard deviation were used. The fact that all comparisons made were significant at the selected alpha level made a supporting case for the conclusion that the weighted composite change score was robust in its discriminating power. With the affirmative answer to question 2, hypothesis two was again supported.

The final procedure selected to validate the space utilization measures consisted of rank order comparisons between the judges' criterion groups and the performance scores on each of the
Table 11

Summary of t Values* Comparing Individual Subjects and Criterion Group Means

<table>
<thead>
<tr>
<th>Criterion Group</th>
<th>Subject No.</th>
<th>Most Expansive Group</th>
<th>Medium Expansive Group</th>
<th>Least Expansive Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most Expansive</td>
<td>3</td>
<td>16.49&lt;sup&gt;c&lt;/sup&gt;</td>
<td>11.82&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td>1</td>
<td>15.66&lt;sup&gt;c&lt;/sup&gt;</td>
<td>11.23&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Medium Expansive</td>
<td>9</td>
<td>13.49&lt;sup&gt;c&lt;/sup&gt;</td>
<td>9.67&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td>20</td>
<td>8.16&lt;sup&gt;c&lt;/sup&gt;</td>
<td>7.38&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Expansive Group</td>
<td>17</td>
<td>9.07&lt;sup&gt;c&lt;/sup&gt;</td>
<td>8.21&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>7.13&lt;sup&gt;c&lt;/sup&gt;</td>
<td>6.45&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Least Expansive</td>
<td>14</td>
<td>5.77&lt;sup&gt;c&lt;/sup&gt;</td>
<td>7.28&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Group</td>
<td>18</td>
<td>4.07&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5.14&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>3.09&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.90&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

*<sup>a</sup>t <sub>.05,3</sub> ≤ 2.35; t <sub>.01,3</sub> ≤ 4.54
*<sup>b</sup>Significant at the .05 level
*<sup>c</sup>Significant at the .01 level

Six measures. The rank order comparison tests were much more rigorous tests for validity than were those employed to determine the discriminating power of the components of the spatial measures. The Spearman Rank correlation coefficient (r<sub>s</sub>) was used in calculating the correlation between the final rank assigned to criterion group subjects, as was presented in Table 6, and the ranking of the subjects' scores on each of the space utilization measures (Refer to Appendix B).

Table 12 shows the comparison of ranks between the judges' ratings of the over-all Movement Task for space utilization and the subjects' rankings on the Linear Distance Traveled measure. The rankings
on the measure of Linear Distance were in greater concordance with the judges' rankings than were the rankings of the scores on any other space utilization measure. The correlation between judges' rankings on space utilization and the rankings on Linear Distance Traveled was \( r_s = .97 \). This correlation was significant beyond the .01 level.

**TABLE 12**

**RANKINGS ON SPACE UTILIZATION AND LINEAR DISTANCE TRAVELED**

(N=9)

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>Space Utilization</th>
<th>Linear Distance Traveled</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>17</td>
<td>5</td>
<td>5 ( r_s = .97^a )</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>14</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>18</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>8</td>
</tr>
</tbody>
</table>

\( ^{a} r_{s,.05} = .60, \quad r_{s,.01} = .78 \)

The correlation between the judges' rankings on space utilization and the score rankings on Level Change, as presented in Table 13, was \( r_s = .78 \) which was significant at the .01 level.

The correlation between the judges' rankings on space utilization and the score rankings on Level Range as a Percentage of Subject's Height was an insignificant \( r_s = .48 \). As evidenced in Table 14, the rankings on the quantitative measure of Level Range as Percentage of Subject's Height deviated more from the
judges' rankings than was the case with the two previous space utilization measures.

### TABLE 13
RANKINGS ON SPACE UTILIZATION AND LEVEL CHANGE (N=9)

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>Space Utilization</th>
<th>Level Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>17</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>14</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>18</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

\[ r_s = .78^a \]

\[ a \text{ } r_{s_{.05}} \geq .60, \text{ } r_{s_{.01}} \geq .78 \]

### TABLE 14
RANKINGS ON SPACE UTILIZATION AND LEVEL RANGE AS A PERCENTAGE OF SUBJECT'S HEIGHT (N=9)

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>Space Utilization</th>
<th>Level Range as Percent of Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>17</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>14</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>18</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

\[ r_s = .48^a \]

\[ a \text{ } r_{s_{.05}} \geq .60, \text{ } r_{s_{.01}} \geq .78 \]
The comparison between the rankings on the quantitative measure, Percentage of Possible Floor Grid Shifts, and the judges' rankings on Space Utilization is summarized in Table 15. The correlation of \( r_s = .86 \) was significant beyond the .01 level.

**TABLE 15**

RANKINGS ON SPACE UTILIZATION AND PERCENTAGE OF FLOOR GRID SHIFTS (N=9)

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>Space Utilization</th>
<th>Percentage of Floor Grid Shifts</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1.5^a</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
<td>1.5^a</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>17</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>14</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>18</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

^aWhen tied scores occurred, each of them was assigned the average of the ranks which would have been assigned had no ties occurred.

^b\( r_{s, .05} \geq .60, \quad r_{s, .01} \geq .78 \)

The correlation between the judges' rankings on Space Utilization and the rankings of the scores on Percentage of Enterable Grid Squares Entered, as presented in Table 16, was \( r_s = .85 \). This correlation was significant beyond the .01 level.
TABLE 16
RANKINGS ON SPACE UTILIZATION AND PERCENTAGE OF ENTERABLE GRID SQUARES ENTERED (N=9)

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>Space Utilization</th>
<th>Percentage of Enterable Grid Squares Entered</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>17</td>
<td>5</td>
<td>8 (rs = .85a)</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>14</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>18</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

*a rs .05 ≥ .60, rs .01 ≥ .78

The correlation between the judges' rankings on space utilization and the rankings on Floor Pattern Range was a high rs = .93 which was significant beyond the .01 level. As evidenced in Table 17 the rankings on the measure of Floor Pattern Range were in high concordance with the judges' rankings.

It is important to point out some of the characteristics of the Spearman Rank Correlation coefficient (rs) which was employed in the preceding six comparisons. The index is not closely connected with the theory of linear regression, nor should the square of this index on ranks be interpreted in the usual way as a proportion of variance accounted for in the underlying variables. It does show "agreement" and does indicate the general "monotonicity" of the underlying
TABLE 17
RANKINGS ON SPACE UTILIZATION AND
FLOOR PATTERN RANGE*
(N=9)

<table>
<thead>
<tr>
<th>Subject No.</th>
<th>Space Utilization</th>
<th>Floor Pattern Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>17</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>14</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>18</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

$r_s = .93^a$

$a_{r_s .05} \geq .60, \quad r_{s .01} \geq .78$

relation. In other words, an increase in the value of one rank always is accompanied by an increase in the corresponding value of the other rank. Linear functions are always monotone, but so are many other functions that are definitely not linear, such as $Y = X^3$ or $Y = \log X$.

In summary, the Spearman Rank Order Correlation does not reflect exactly the same characteristics as $r_{XY}$ or $r^2_{XY}$.

With these general explanations in mind, it was concluded that five of the six quantitative measures of space utilization were significantly correlated with the over-all quality of space utilization as judged by three experts. Level Range as a Percentage of Subject's Height was the only measure insignificantly correlated with the judges' rankings.
In summary, the validation procedures employed to experimentally evaluate the method proposed to analyze space utilization yielded results which suggested that the method was highly discriminating and accurate. The validity analysis unquestionably supported hypothesis two, which stated that by applying the proposed method to unstructured movement the spatial dimensions of movement could be quantified to validly assess space utilization. Some caution should be applied in any future use of the space utilization measure called Level Range as a Percentage of Subject's Height. Even though this measure did not withstand the more rigorous rank correlation test, it is concluded that the discriminating power of the measure is high, and, therefore, could contribute valuable information to future analytic studies.

Trend Analysis and Reliability Estimates of the Space Utilization Measures

The data for trials 2-5 on the Movement Task were subjected to a trend analysis test for each of the six quantitative measures used to assess space utilization. Based upon the findings reported in Tables 18-23, none of the F values for the six measures was significant at the .05 level. There were no non-random effects present, and thus, no trend effects across the trials appeared.

The intraclass correlation formula for estimating reliability was consequently altered to include the trial variance in the subjects x trials variance term. The resulting combination of trial variance and subjects x trials variance provided the variance term usually referred to as "within subjects" variance. Although the
interclass correlation coefficient was deflated as a result of this more precise modification, a more accurate estimate of the reliability was obtained by using the following formula:

\[ R = \frac{MS_{between\ subjects} - MS_{within\ subjects}}{MS_{between\ subjects}} \]

Table 18 presents the summary of the trend analysis and reliability estimate on the spatial measure called Linear Distance Traveled. The trial effect represented by an F value of .69 was not significant. The intraclass correlation (R) was estimated at .88 which is very high.

**TABLE 18**

**SUMMARY OF TREND ANALYSIS AND RELIABILITY COEFFICIENT FOR LINEAR DISTANCE TRAVELED, TRIALS 2-5**

(N=21)

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Subjects</td>
<td>192,271.02</td>
<td>20</td>
<td>9613.55</td>
<td>.88</td>
<td></td>
</tr>
<tr>
<td>Within Subjects</td>
<td>72,097.51</td>
<td>63</td>
<td>1144.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Trials</td>
<td>2,388.16</td>
<td>3</td>
<td>796.05</td>
<td>.69*</td>
<td></td>
</tr>
<tr>
<td>Subjects x Trials</td>
<td>69,709.35</td>
<td>60</td>
<td>1161.82</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>264,368.53</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Refer to Appendix E.*
Table 19 shows there was no trial effect present on the spatial measure called Level Change. An intraclass correlation coefficient of .83 was obtained.

**TABLE 19***

**SUMMARY OF TREND ANALYSIS AND RELIABILITY COEFFICIENT FOR LEVEL CHANGE, TRIALS 2-5**

(N=21)

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Subjects</td>
<td>3757.00</td>
<td>20</td>
<td>187.85</td>
<td></td>
<td>.83</td>
</tr>
<tr>
<td>Within Subjects</td>
<td>1972.10</td>
<td>63</td>
<td>31.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Trials</td>
<td>191.48</td>
<td>3</td>
<td>63.83</td>
<td>2.15a</td>
<td></td>
</tr>
<tr>
<td>Subjects x Trials</td>
<td>1780.62</td>
<td>60</td>
<td>29.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5729.10</td>
<td>83</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Refer to Appendix E.*
### TABLE 20*

**SUMMARY OF TREND ANALYSIS AND RELIABILITY COEFFICIENT FOR LEVEL RANGE AS A PERCENTAGE OF SUBJECT'S HEIGHT, TRIALS 2-5 (N=21)**

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Subjects</td>
<td>19,627.61</td>
<td>20</td>
<td>981.38</td>
<td>.80</td>
<td></td>
</tr>
<tr>
<td>Within Subjects</td>
<td>12,625.08</td>
<td>63</td>
<td>200.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Trials</td>
<td>826.40</td>
<td>3</td>
<td>275.47</td>
<td>1.40</td>
<td></td>
</tr>
<tr>
<td>Subjects x Trials</td>
<td>11,798.68</td>
<td>60</td>
<td>196.64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>32,252.69</td>
<td>83</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*F *<0.05 (3,60) ≥ 2.76

### TABLE 21*

**SUMMARY OF TREND ANALYSIS AND RELIABILITY COEFFICIENT FOR PERCENTAGE OF POSSIBLE FLOOR GRID SHIFTS, TRIALS 2-5 (N=21)**

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Subjects</td>
<td>6219.98</td>
<td>20</td>
<td>311.00</td>
<td>.75</td>
<td></td>
</tr>
<tr>
<td>Within Subjects</td>
<td>4968.48</td>
<td>63</td>
<td>78.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Trials</td>
<td>175.29</td>
<td>3</td>
<td>58.43</td>
<td>.73</td>
<td></td>
</tr>
<tr>
<td>Subjects x Trials</td>
<td>4793.19</td>
<td>60</td>
<td>79.89</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>11,188.46</td>
<td>83</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*F *<0.05 (3,60) ≥ 2.76

*Refer to Appendix E.*
Table 22 summarizes the analysis which yielded a non-significant trial effect for the measure called Percentage of Enterable Grid Squares Entered. The moderate reliability estimate of .72 was obtained on this measure.

**TABLE 22**

**SUMMARY OF TREND ANALYSIS AND RELIABILITY COEFFICIENT FOR PERCENTAGE OF ENTERABLE GRID SQUARES ENTERED, TRIALS 2-5 (N=21)**

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Subjects</td>
<td>8908.83</td>
<td>20</td>
<td>445.44</td>
<td>.72</td>
<td></td>
</tr>
<tr>
<td>Within Subjects</td>
<td>7777.05</td>
<td>63</td>
<td>123.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Trials</td>
<td>55.71</td>
<td>3</td>
<td>18.57</td>
<td>.14a</td>
<td></td>
</tr>
<tr>
<td>Subjects x Trials</td>
<td>7721.34</td>
<td>60</td>
<td>128.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>16,685.88</strong></td>
<td><strong>83</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*aF.05 (3,60) \(\geq\) 2.76

The trial effect across the four trials on Floor Pattern Range also resulted in a non-significant F value as presented in Table 23. The reliability estimate on this measure as calculated by the intra-class correlation coefficient was .64, the lowest estimate of the six spatial measures.

*Refer to Appendix E.*
TABLE 23*
SUMMARY OF TREND ANALYSIS AND RELIABILITY COEFFICIENT FOR FLOOR PATTERN RANGE, TRIALS 2-5
(N=21)

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Subjects</td>
<td>737.67</td>
<td>20</td>
<td>36.88</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Within Subjects</td>
<td>845.96</td>
<td>63</td>
<td>13.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Trials</td>
<td>22.18</td>
<td>3</td>
<td>7.39</td>
<td>54a</td>
<td></td>
</tr>
<tr>
<td>Subjects x Trials</td>
<td>823.78</td>
<td>60</td>
<td></td>
<td>13.73</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1583.63</td>
<td>83</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Refer to Appendix B.

A firm understanding of the intraclass correlation coefficient (R) is important in interpreting the reliability estimates of the six spatial measures in the preceding analyses. One interpretation is that if the same spatial measure were to be repeated with another sample of four trials, but with the same subjects, the correlation between the mean scores obtained from the two sets of data on the same subjects would be approximately the same value as the computed R for that particular measure. Secondly, the index is another way of expressing the proportion of variance attributable to the factor of subjects, similar to two other indices, the Greek omega, squared and the Pearson $r_{xy}$, squared.

*Refer to Appendix B.
It is common to hear statisticians give value interpretations of reliability coefficient ranges. Generally, coefficients ranging from .80 to .89 are considered fairly high and adequate for individual measurements, while coefficients ranging from .70 to .79 are interpreted as being moderately low, but adequate for group measurement. Below .70, reliability coefficients are considered low and only useful for group averages and surveys. Statisticians who purport these value interpretations subscribe to the common procedure of using the Pearson-Product Moment correlation method to estimate reliability. While this method is less accurate and seldom appropriate, the typical value interpretations of reliability coefficients are in fact based upon these inflated Pearson r coefficients. It is for this reason that modifications in the interpretations of the preceding reliability coefficients must be made.

The measure of space utilization called Floor Pattern Range was estimated to have a moderately low reliability of .64, while two measures with reliability estimates of .72 and .75 appeared quite substantial and adequate for further analytic application. The reliability estimates ranging from .80 to .88 for three of the space utilization measures were very high and quite good.

Because the development of new evaluation tools and analytic instruments demands the most reliable measures possible, increased reliability estimates of the proposed measures in this investigation may be attempted through additional refinement of the instruments. Further study may show, however, that the reliability estimates on
these characteristics of human behavior will consistently appear in
the same range thereby indicating that the relative consistency of
human performance in tasks eliciting free, open-ended, creative
responses may always be more varied, and, therefore, will appear
slightly lower than reliability estimates of other motor tasks
typically involving a time factor or measuring a maximum effort.
CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

This study proposed to develop and validate a method for measuring the three-dimensional space utilization of unstructured human movement.

The proposed method required the development of video-tape analysis techniques to obtain the three-dimensional data and the development of adequate mathematical corrections for variations in body part locations due to photographic perspective. A computer program was developed for the calculations of such corrections as well as for the calculation of the selected measures of space utilization. The quantitative measures devised for the analysis of space utilization included the following:

A. Linear Distance Traveled
B. Level Change
C. Level Range as a Percentage of Subject's Height
D. Percentage of Possible Floor Grid Shifts
E. Percentage of Enterable Grid Squares Entered
F. Floor Pattern Range

An experimental evaluation was conducted of the proposed space utilization measures in order to test their validity and reliability.

Twenty-one volunteer college men and women enrolled at Beloit College were involved in this study. The data required to complete this study were obtained by video-taping from two views the subjects' Movement Task performed within a floor area measuring 22 feet by 28 feet. One television camera was positioned directly overhead,
and the other television camera was positioned on the floor in such a manner that their optical axes intersected and were perpendicular to one another.

Analysis of the video-taped views yielded $x, y, z$ coordinates which were corrected for depth perspective error and which were used in determining the true $X, Y, Z$ spatial coordinates. Three judges were employed to independently evaluate the camera views of each subject’s Movement Task performance with the preface that they were to select and rank the three subjects best representative of each of the following groups: 1) performers using the most amount of space in all three planes (referred to as the "most expansive" group); 2) performers using the least amount of space in all three planes (referred to as the "least expansive" group); and 3) performers using an intermediate amount of space in all three planes (referred to as the "medium expansive" group).

The results of the Pilot Study showed the best sampling interval in order to maximize accuracy and minimize work cost in the video-tape analysis to be four seconds.

Reliability estimates for the tape analysis procedures were extremely high. The Pearson-Product Moment correlation method yielded inter-observer reliabilities ranging from $r = .96$ to $r = .98$ for the three-dimensional space coordinates. Intra-observer reliabilities were estimated by an analysis of variance method yielding an intraclass correlation coefficient and also by the Pearson-Product Moment correlation method. Reliabilities performed on the
x, y, z spatial coordinates data by the two methods ranged from R = .986 to R = .999 and r = .973 to r = .998.

Employing Kendall's coefficient of concordance, judges' rankings of subjects within each previously judged criterion group were compared for over-all agreement. The inter-judge reliability index, W = 9.85, was significant beyond the .01 level.

The validity of the six space utilization measures was analyzed by comparing the quantitative scores on each measure with the judges' over-all rankings of space utilization on the Movement Task for the criterion group subjects. The following five space utilization measures had high correlations with the judges' rankings: Linear Distance Traveled; Level Change; Percentage of Floor Grid Shifts; Percentage of Enterable Grid Squares Entered; and Floor Pattern Range. All comparisons were significant at the .01 level. The comparison of the measure termed Level Range as a Percentage of Subject's Height and the judges' rankings was within the bounds of that which could be expected by chance alone.

The other procedure used to validate the space utilization measures consisted of determining the discrimination power of the changes in spatial coordinates (location changes due to three-dimensional movement) when compared to the criterion groups. An analysis of variance and post-hoc comparisons using the Scheffe method were used in making the group mean comparisons. The weighted composite change score discriminated at the .05 level of significance between each of the criterion group means. The comparison between each subject's change in spatial coordinates and each of the non-inclusive criterion groups provided the basis for determining
another phase of the discrimination power. On the basis of t tests, all comparisons made were significant at the .05 level; many comparisons met the more rigorous .01 level of significance.

Estimates of the reliability of each of the selected space utilization measures were based upon an analysis of variance technique yielding an intraclass correlation coefficient. The reliability estimate for Floor Pattern Range was $R = .64$ which is moderately low, but this measure could be used for some group averages and analysis even before any refinement. Substantial reliability estimates of .72 and .75, respectively, were obtained for the space utilization measures called Percentage of Enterable Grid Squares Entered and Percentage of Possible Floor Grid Shifts. The following three space utilization measures were found to have quite high reliability estimates .80, .83, and .88, respectively: Level Range as Percentage of Subjects' Height; Level Change; and Linear Distance Traveled.

Trend analysis tests across the four trials of each of the six quantitative measures resulted in non-significant $F$ values. No non-random effects were present, and therefore, no trend effects across the trials appeared.

**Conclusions**

Within the limitations of this study, the following conclusions seem justifiable:

1. A reliable method for locating three-dimensional spatial coordinates correcting for complex photographic perspective can be developed using a two-camera video-tape system.
2. Statistical results unquestionably suggest that measures can be quantified in order to assess validly space utilization.

3. Statistical results verify that the space utilization measures developed herein exhibit substantial reliability coefficients. Caution must be imparted, however, when employing the Floor Pattern Range measure which had the lowest reliability estimate.

**Recommendations**

There is a need for further study regarding three-dimensional spatial analysis of unstructured movement. The writer recommends that future studies be expanded to consider the other spatial components of movement such as: directionality preference, use of individual body parts and combinations of body parts; and analysis of pathway angularity. One major consideration must be the adequacy of the instrumentation employed for the analysis.

It is recommended that the method developed in this study serve as a model for the quantitative analysis of other movement components, namely time and force, with a view toward developing a complete taxonomy and theory of the structure of movement.

It is recommended that the exact movement instrument posed in this study be used as a basis for exploring the assessment of extraversion as a personality variable, and for exploring the assessment of motor creativity.

Numerous other specific questions relating to changes imposed upon the administration of the Movement Task remain to be investigated.
Many possibilities exist for further research employing the proposed method and movement instrument by studying the effects of such variables as age, sex, dance experience, verbal creativity, and various social factors.
APPENDIXES
APPENDIX A

ACTIVITY BACKGROUND QUESTIONNAIRE

NAME ________________________ BIRTHDATE _______________ AGE ________

1. Please check any of the following activities in which you have received instruction while in school (elementary, secondary, college).

   Also indicate the number of months or years of instruction, your age during instruction, and what level of instruction, i.e., beginning, intermediate, or advanced.

   Folk & Square Dance _________ Wrestling (men) _________
   Tap Dance ________ Tumbling ________
   Social Dance _________ Judo/Karate ________
   Modern Dance ________ Free Exercise ________
   Modern Jazz ________ Baton Twirling ________
   Ballet _______ Stage Acting ________

2. Have you participated in any of the above activities for any length of time "on your own" following initial instruction? This may mean in the form of club, team, or recreation participation. Please explain level of involvement and duration.

3. Have you ever taken private dancing lessons? YES ___ NO ___

   What kind(s)?
   How long?
   At what age(s)?

   Individual lessons? ____ Group lessons? ____

4. Have you ever taken private lessons in any of the above listed activities other than dancing lessons? YES ___ NO ___

   What kind of lessons?
   How long?
   At what age(s)?

5. Have you any experience in composing or choreographing a dance composition? ____ A free exercise routine? ____ Please explain.
APPENDIX B

INSTRUCTIONS FOR PERFORMANCE OF MOVEMENT TASK

The context of the tape recording to which each subject listened prior to the Movement Task follows:

I have asked several students on campus to assist me for about thirty minutes. The purpose of having each of you come to the Fieldhouse and do a little moving is to help me acquire some new ideas about movement patterns.

Which ever way you choose to move and anything you choose to do are acceptable. I cannot emphasize this enough; nothing will be incorrect.

Before we begin, notice the white taped rectangle I have established on the floor as your limits. I would like you to use this area for your movement; try not to exceed the boundaries. It is essential that your movement be photographed by both the overhead camera and the floor camera. It will be fun for you to see the two different video-taped views of yourself at a later date.

Will you now assume a sitting position on the tape marking in the center of the rectangle...(pause)...From this point, you are free to move wherever you wish within the rectangle. There will be no recorded music or imposed beat for you to follow or interpret. As soon as I tell you to "begin!", just start moving. It's as simple as that. When I give you a signal to "stop!", pause momentarily where you are, and then you will be asked to reposition yourself on the tape mark in the center, and wait for the next "start" signal. You will be given five opportunities to move. Each time, forget about me and the cameras, and direct your thoughts to your movements. Feel very free to do anything you wish.

Do you have any questions?........(pause)........Then wait until I give you the starting signal before you begin moving.
APPENDIX C

GUIDELINES TO JUDGES FOR EVALUATING VIDEO-TAPES

The following suggestions for rating the video-tapes were presented in writing to each of the three dance experts who served as judges.

SUGGESTIONS FOR VIEWING MOVEMENT IMPROVISATIONS

1. Try to get an over-all, global impression of the amount of space used in the movement pattern that is presented to you. Attempt to combine your impressions of the distances and ranges of movement in each of the three spatial planes.

A. Your primary concern should be where the body is moving, not what specific parts of the body are moving.

For an indication of the amount of space used, look for the changing locations of the body in relation to three particular planes of movement:

(1) Be aware of the location change that takes place from the front to the back of the stage as the body moves in this plane referred to as depth. You will notice the body move closer to you and farther away from you as it passes over the grid squares on the floor.

(2) You will also see the body change location in relation to the horizontal plane as you watch the body move from one side of the television monitor to the other side. For example, the body may move across the floor grids from your left to your right.

(3) In watching location change in the up and down plane, referred to as the vertical plane, notice the amount of change in the body level by observing the change in location of the highest body part. Sometimes an impression of a high level will be gained from extended arms overhead while the body is in a standing position, as contrasted with a lower level position in which the body may be prone on the floor with one leg extended upward.

B. Try to disregard how the body moves; the style, the quality, and the shape are not important to your impression and rating.
Guidelines to Judges for Evaluating Video-Tapes

Try to lose sight of the mover as a person, and look at him rather as an impersonal force in motion. The what or content of the movement should be disregarded in lieu of observing the where of the movement.

2. Try to see what impressions you get from how much space the body moves through in ALL three planes of movement as they merge together in a total configuration.

A. Don't look analytically for one-to-one relations; don't try to estimate distances.

B. Rather try to experience how extensive the total body movement is in terms of distances covered in each of the three spatial planes.
APPENDIX D

MEAN SCORES OF TRIALS 2-5 ON HORIZONTAL CHANGE, VERTICAL CHANGE, DEPTH CHANGE AND THEIR WEIGHTED COMPOSITE (N=9)

<table>
<thead>
<tr>
<th>Criterion Group</th>
<th>Subject No.</th>
<th>Horizontal Change Score (x coordinate)</th>
<th>Vertical Change Score (y coordinate)</th>
<th>Depth Change Score (z coordinate)</th>
<th>Weighted Composite Change Score (.25x + .50y + .25z)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most Expansive</td>
<td>3</td>
<td>103.00</td>
<td>22.00</td>
<td>56.75</td>
<td>50.94</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>92.75</td>
<td>19.13</td>
<td>62.50</td>
<td>48.38</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>87.00</td>
<td>17.00</td>
<td>45.75</td>
<td>41.69</td>
</tr>
<tr>
<td>Medium Expansive</td>
<td>20</td>
<td>51.50</td>
<td>20.50</td>
<td>34.75</td>
<td>31.81</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>60.75</td>
<td>25.25</td>
<td>30.25</td>
<td>35.38</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>52.00</td>
<td>16.75</td>
<td>25.75</td>
<td>27.81</td>
</tr>
<tr>
<td>Least Expansive</td>
<td>14</td>
<td>40.75</td>
<td>12.25</td>
<td>24.75</td>
<td>22.50</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>30.50</td>
<td>7.63</td>
<td>17.75</td>
<td>15.88</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>21.50</td>
<td>5.75</td>
<td>15.25</td>
<td>12.06</td>
</tr>
</tbody>
</table>
### APPENDIX E

**RAW SCORES BY TRIAL ON SPACE UTILIZATION MEASURES**

(N=21)

<table>
<thead>
<tr>
<th>Subject Height (^2)</th>
<th>Measure A</th>
<th>Measure B</th>
<th>Measure C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(T_2)</td>
<td>(T_3)</td>
<td>(T_4)</td>
</tr>
<tr>
<td>1</td>
<td>5.58</td>
<td>236.28</td>
<td>204.70</td>
</tr>
<tr>
<td>2</td>
<td>5.25</td>
<td>74.37</td>
<td>38.77</td>
</tr>
<tr>
<td>3</td>
<td>5.37</td>
<td>236.67</td>
<td>228.65</td>
</tr>
<tr>
<td>4</td>
<td>5.54</td>
<td>125.30</td>
<td>168.57</td>
</tr>
<tr>
<td>5</td>
<td>5.39</td>
<td>112.87</td>
<td>85.99</td>
</tr>
<tr>
<td>6</td>
<td>5.58</td>
<td>111.49</td>
<td>130.42</td>
</tr>
<tr>
<td>7</td>
<td>5.16</td>
<td>120.28</td>
<td>85.57</td>
</tr>
<tr>
<td>8</td>
<td>5.25</td>
<td>68.63</td>
<td>97.61</td>
</tr>
<tr>
<td>9</td>
<td>5.58</td>
<td>220.85</td>
<td>143.33</td>
</tr>
<tr>
<td>10</td>
<td>5.41</td>
<td>180.24</td>
<td>211.20</td>
</tr>
<tr>
<td>11</td>
<td>5.92</td>
<td>140.41</td>
<td>98.01</td>
</tr>
<tr>
<td>12</td>
<td>5.29</td>
<td>67.44</td>
<td>93.49</td>
</tr>
<tr>
<td>13</td>
<td>5.83</td>
<td>216.29</td>
<td>146.09</td>
</tr>
<tr>
<td>14</td>
<td>5.00</td>
<td>47.28</td>
<td>72.17</td>
</tr>
<tr>
<td>15</td>
<td>5.60</td>
<td>165.73</td>
<td>170.46</td>
</tr>
<tr>
<td>16</td>
<td>5.25</td>
<td>171.83</td>
<td>110.19</td>
</tr>
<tr>
<td>17</td>
<td>5.58</td>
<td>82.12</td>
<td>228.34</td>
</tr>
<tr>
<td>18</td>
<td>5.69</td>
<td>51.02</td>
<td>50.51</td>
</tr>
<tr>
<td>19</td>
<td>6.08</td>
<td>96.57</td>
<td>132.87</td>
</tr>
<tr>
<td>20</td>
<td>5.50</td>
<td>129.60</td>
<td>129.92</td>
</tr>
<tr>
<td>21</td>
<td>5.13</td>
<td>83.56</td>
<td>76.07</td>
</tr>
</tbody>
</table>

1

Measure A represents Linear Distance Traveled in Feet
Measure B represents Level Change in Feet
Measure C represents Level Range as a Percentage of Subject's Height

2

Height measured in Feet
### APPENDIX E (continued) 1

**RAW SCORES BY TRIAL ON SPACE UTILIZATION MEASURES**

(N=21)

<table>
<thead>
<tr>
<th>Subject</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
<th>Ave.</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
<th>Ave.</th>
<th>T2</th>
<th>T3</th>
<th>T4</th>
<th>T5</th>
<th>Ave.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>95.83</td>
<td>91.66</td>
<td>91.66</td>
<td>100.00</td>
<td>94.79</td>
<td>24.93</td>
<td>24.97</td>
<td>23.05</td>
<td>23.28</td>
<td>24.06</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>78.26</td>
<td>39.13</td>
<td>78.26</td>
<td>73.91</td>
<td>67.39</td>
<td>75.00</td>
<td>37.50</td>
<td>70.83</td>
<td>75.00</td>
<td>64.58</td>
<td>21.58</td>
<td>13.54</td>
<td>24.54</td>
<td>22.69</td>
<td>20.56</td>
</tr>
<tr>
<td>3</td>
<td>95.65</td>
<td>95.65</td>
<td>95.65</td>
<td>95.65</td>
<td>95.65</td>
<td>87.50</td>
<td>87.50</td>
<td>81.33</td>
<td>91.66</td>
<td>87.50</td>
<td>27.54</td>
<td>26.37</td>
<td>21.85</td>
<td>25.52</td>
<td>25.32</td>
</tr>
<tr>
<td>4</td>
<td>100.00</td>
<td>100.00</td>
<td>95.65</td>
<td>95.65</td>
<td>97.82</td>
<td>87.50</td>
<td>91.66</td>
<td>79.16</td>
<td>91.66</td>
<td>87.50</td>
<td>26.49</td>
<td>25.85</td>
<td>25.66</td>
<td>23.99</td>
<td>25.50</td>
</tr>
<tr>
<td>5</td>
<td>91.30</td>
<td>91.30</td>
<td>86.95</td>
<td>100.00</td>
<td>92.39</td>
<td>79.16</td>
<td>87.50</td>
<td>79.16</td>
<td>75.00</td>
<td>80.20</td>
<td>19.53</td>
<td>23.01</td>
<td>20.91</td>
<td>23.03</td>
<td>21.62</td>
</tr>
<tr>
<td>6</td>
<td>73.91</td>
<td>86.95</td>
<td>91.30</td>
<td>60.86</td>
<td>78.26</td>
<td>66.66</td>
<td>70.83</td>
<td>83.33</td>
<td>54.16</td>
<td>68.75</td>
<td>21.41</td>
<td>26.60</td>
<td>30.08</td>
<td>24.28</td>
<td>25.59</td>
</tr>
<tr>
<td>7</td>
<td>95.65</td>
<td>82.60</td>
<td>91.30</td>
<td>95.65</td>
<td>91.30</td>
<td>83.33</td>
<td>75.00</td>
<td>70.83</td>
<td>83.33</td>
<td>78.12</td>
<td>22.00</td>
<td>17.09</td>
<td>17.58</td>
<td>22.00</td>
<td>19.67</td>
</tr>
<tr>
<td>8</td>
<td>95.65</td>
<td>91.30</td>
<td>56.52</td>
<td>65.21</td>
<td>77.17</td>
<td>83.33</td>
<td>75.00</td>
<td>37.50</td>
<td>37.50</td>
<td>58.33</td>
<td>20.28</td>
<td>21.01</td>
<td>9.91</td>
<td>11.59</td>
<td>15.70</td>
</tr>
<tr>
<td>9</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
<td>95.83</td>
<td>75.00</td>
<td>87.50</td>
<td>79.16</td>
<td>80.20</td>
<td>28.04</td>
<td>19.15</td>
<td>20.48</td>
<td>21.39</td>
<td>22.27</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>95.65</td>
<td>95.65</td>
<td>100.00</td>
<td>100.00</td>
<td>98.91</td>
<td>83.33</td>
<td>95.83</td>
<td>87.50</td>
<td>88.54</td>
<td>27.85</td>
<td>26.04</td>
<td>23.15</td>
<td>21.42</td>
<td>24.61</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>91.30</td>
<td>91.30</td>
<td>95.65</td>
<td>91.30</td>
<td>92.39</td>
<td>79.16</td>
<td>62.50</td>
<td>79.16</td>
<td>66.66</td>
<td>71.87</td>
<td>19.82</td>
<td>13.24</td>
<td>22.28</td>
<td>18.68</td>
<td>18.50</td>
</tr>
<tr>
<td>12</td>
<td>86.95</td>
<td>91.30</td>
<td>95.65</td>
<td>73.91</td>
<td>86.95</td>
<td>50.00</td>
<td>79.16</td>
<td>83.33</td>
<td>75.00</td>
<td>71.87</td>
<td>17.98</td>
<td>25.72</td>
<td>26.64</td>
<td>23.32</td>
<td>23.41</td>
</tr>
<tr>
<td>13</td>
<td>95.65</td>
<td>82.60</td>
<td>95.65</td>
<td>95.65</td>
<td>92.39</td>
<td>83.33</td>
<td>66.66</td>
<td>95.83</td>
<td>87.50</td>
<td>83.33</td>
<td>26.79</td>
<td>22.81</td>
<td>23.87</td>
<td>23.83</td>
<td>24.33</td>
</tr>
<tr>
<td>14</td>
<td>86.95</td>
<td>95.65</td>
<td>91.30</td>
<td>91.30</td>
<td>91.30</td>
<td>45.83</td>
<td>83.33</td>
<td>66.66</td>
<td>83.33</td>
<td>69.79</td>
<td>8.78</td>
<td>13.90</td>
<td>21.21</td>
<td>24.93</td>
<td>17.21</td>
</tr>
<tr>
<td>15</td>
<td>100.00</td>
<td>95.65</td>
<td>100.00</td>
<td>95.65</td>
<td>97.82</td>
<td>95.83</td>
<td>87.50</td>
<td>87.50</td>
<td>85.58</td>
<td>24.72</td>
<td>26.03</td>
<td>27.04</td>
<td>25.53</td>
<td>25.83</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>100.00</td>
<td>95.65</td>
<td>95.65</td>
<td>100.00</td>
<td>97.82</td>
<td>91.66</td>
<td>95.83</td>
<td>79.16</td>
<td>95.83</td>
<td>90.62</td>
<td>21.39</td>
<td>27.00</td>
<td>26.70</td>
<td>26.78</td>
<td>25.47</td>
</tr>
<tr>
<td>17</td>
<td>82.60</td>
<td>91.30</td>
<td>100.00</td>
<td>56.52</td>
<td>82.60</td>
<td>66.66</td>
<td>70.83</td>
<td>75.00</td>
<td>41.66</td>
<td>63.54</td>
<td>19.16</td>
<td>23.71</td>
<td>21.39</td>
<td>12.32</td>
<td>15.15</td>
</tr>
<tr>
<td>18</td>
<td>86.95</td>
<td>82.60</td>
<td>82.60</td>
<td>95.65</td>
<td>86.95</td>
<td>58.33</td>
<td>62.50</td>
<td>70.83</td>
<td>79.16</td>
<td>67.70</td>
<td>19.72</td>
<td>15.26</td>
<td>19.26</td>
<td>20.99</td>
<td>18.81</td>
</tr>
<tr>
<td>19</td>
<td>100.00</td>
<td>100.00</td>
<td>95.65</td>
<td>82.60</td>
<td>94.56</td>
<td>87.50</td>
<td>83.33</td>
<td>83.33</td>
<td>66.66</td>
<td>80.20</td>
<td>24.85</td>
<td>19.86</td>
<td>25.48</td>
<td>13.77</td>
<td>20.99</td>
</tr>
<tr>
<td>20</td>
<td>91.30</td>
<td>95.65</td>
<td>86.95</td>
<td>100.00</td>
<td>93.47</td>
<td>75.00</td>
<td>75.00</td>
<td>83.33</td>
<td>70.83</td>
<td>76.04</td>
<td>20.45</td>
<td>21.10</td>
<td>23.10</td>
<td>19.24</td>
<td>20.97</td>
</tr>
<tr>
<td>21</td>
<td>82.60</td>
<td>82.60</td>
<td>73.91</td>
<td>78.26</td>
<td>79.34</td>
<td>70.83</td>
<td>66.66</td>
<td>62.50</td>
<td>58.33</td>
<td>64.58</td>
<td>26.46</td>
<td>23.82</td>
<td>19.87</td>
<td>18.31</td>
<td>22.11</td>
</tr>
</tbody>
</table>

1 Measure D represents Percentage of Possible Floor Grid Shifts  
Measure E represents Percentage of Enterable Grid Squares Entered  
Measure F represents Floor Pattern Range in Feet
APPENDIX F

SOURCE LISTING OF COMPUTER PROGRAM

// JOB X X X
// FOR DUMMY

*IDCS(CARD, TYPEWRITER, KEYBOARD, 1443 PRINTER, DISK)
*UNPROCESS PROGRAM
*ONE WORD INTEGERS

*LIST SOURCE PROGRAM

C MOVEMENT PATTERNS -- SHIRL AHRENS
C INT=01 MEANS 2 SEC INTERVALS. INT = 02 MEANS 4 SEC INTERVALS

DIMENSION N(3,32), M(4), NN(3,16), A(J,16), B(3,16), D(3,16), AL(4), AV(4)
1, AVR(4), NAT(4,3), ALC(4), AUL(4), FPR(A), Q(48,2)

READ(2,3) INT

NPG=3
1 FORMAT (16(A1,12),211,4A2)
101 NPG=NPG+1

DO 21 NPAS=1,4
C READ 3 FLOOR GRID POSITION CDS HORIZONTAL LETTER, F-B NUMBER A1=L.BACK
DO 21=1,3
C D O 21 NPAS=1,4

2 READ (2,1) (N(1,J),J=1,32),J,J,(M(K),K=1,4)
3 FORMAT (1612)
C READ 3 HEIGHT CARDS DATA FROM FLOOR=0
DO 4 I=1,3
4 READ (2,3) (NN(I,K),K=1,16)
C HEIGHT IS IN 1/2 FOOT UNITS, AS .5,1.0,1.5,2.0, ETC.
DO 5 I=1,3
DO 5 K=1,16

A(I,K)=NN(I,K)
5 C FLOOR HORIZONTAL SHIFT IS #2, -15 50 RANGE IS -13 TO +13
DO 6 I=1,3
DO 6 K=1,16

L NK#2=1
C MAKE ALPHAS CONTINUOUS
1F(N(I,L)+12000)=6,6,51
51 N(I,L)=N(I,L)-1792
6 D(I,K)=(N(I,L)+16320)/128-15
C FLOOR F-B SHIFT IS #2, -12,
DO 7 I=1,3
DO 7 K=1,16

L NK#2=1
7 U(I,K)=N(I,L)#2-12.0
C ADJUST VALUES FOR CAMERA DISTORTION, 1ST FRONT AND TOP F-B, THEN SIDE
DO 8 I=1,3
DO 8 K=1,16,INT
AA=A(I,K)/10.0-4.0
BB=B(I,K)
C HEIGHT
A(I,K)=AA-BB*(AA/85.67)/(1-BB/35.67#AA/85.67)
C DEPTH
B(I,K)=BB-AA#BB/35.67/(1-BB/35.67#AA/85.67)
C HORIZONTAL
8 D(I,K)=B(I,K)X(1-A(I,K)/35.67)
C ACCUMULATE SUM OF LATERAL DISTANCE INTO AL
AL(NPAS)=0
DO 9 I=1,3
DO 9 J=2,16,INT
KN=K-1=INT+1
KND=KN-INT

BB=B(I,K)-D(I,KND)
DD=D(I,KND)-D(I,KND)
9 AL(NPAS)=AL(NPAS)+SORT(BB#BB#DD#DD)
APPENDIX F (continued)

SOURCE LISTING OF COMPUTER PROGRAM

```plaintext
C ACCUMULATE SUM OF VERTICAL DISTANCE INTO AV
AV(NPAS)=0
LMT=16/INT-1
DO 10 I=1,3
DO 10 K=1*LMT
KN=(K-1)*INT+1
KNO=KN+INT
10 AV(NPAS)=AV(NPAS)+ABS(A(I,KN)-A(I,KNO))
C CALCULATE VERTICAL MOTION RANGE
AVR(NPAS)=0
WEF=10000
BIG=0
DO 14 I=1,3
DO 14 K=1,16,INT
IF (A(I,K)-WEF) 11,12,12
WEF=A(I,K)
11 CONTINUE
AVR(NPAS)=BIG-WEF
C CALCULATE NUMBER SQUARES ENTERED TIMES NUMBER TIMES ENTERED
DO 15 I=1,4
NAT(I,3)=0
DO 15 K=1,2
15 NAT(I,K)=999
ND=999
NH=999
AUL(NPAS)=0
LIN=1
DO 19 I=1,3
DO 19 K=1,16,INT
ND=(B(I,K)+13.)/2.
NH=(D(I,K)+15.)/2.
IF (ND-ND) 152,151,152
151 IF (NH-NH) 152,19,152
152 ND=ND
NH=NH
DI(191 KIK=1,LIN
IF (NAT(KIK,1)-ND) 191,16,191
16 IF (NAT(KIK,2)-NH) 191,17,191
17 NAT(KIK,3)=NAT(KIK,3)+1
GO TO 19
191 CONTINUE
NAT(LIN,1)=ND
NAT(LIN,2)=NH
NAT(LIN,3)=1
LIN=LIN+1
19 CONTINUE
NAT(1,3)=NAT(1,3)-1
AUL(NPAS)=LIN-1
DO 20 KIK=1,LIN
Z=NAT(KIK,3)
20 AUL(NPAS)=AUL(NPAS)+Z
C GET MAX RANGE OF EXPANSE FOR SET OF 3 SEGMENTS
FPR(NPAS)=0
LIN=16+3/INT
K=0
FPR(NPAS)=0
```

APPENDIX F (continued)

SOURCE LISTING OF COMPUTER PROGRAM

DO 32 I=1,3
DO 32 J=1,16,INT
K=K+1
Q(K,1)=H(I,J)
32 DO 31 J=1,LIM
DO 31 I=1,LIM
BB=Q(1,I)-Q(1,J)
DD=Q(1,2)-Q(1,2)
Z=SQRT(BB**2+DD**2)
30 IF(FH(NPAS)-Z)30,31,31
31 CONTINUE
AA=16*3/INT-1
ALC(NPAS)=ALC(NPAS)/AA*100.0
AA=AA+1.0
AUL(NPAS)=AUL(NPAS)/AA*100.0
21 CONTINUE
IF(NPAS-3)197,197,198
197 WRITE (3,199)
NPAS=1
199 FORMAT (111)
201 FORMAT ("O TEST PRINT FOR 'A2,29X,'2','12X,'3','12X,'4','12X,'5','11X
1,'TOT,'11X,'AV")
197 WRITE (3,201) (M(K),K=1,4)
AA=0
202 FORMAT ("LINEAR DIST 2-5 + TOT + AV='15X,6F13.2")
DO 203 I=1,4
203 AA=AA+AL(I)
BB=AA/4.0
WRITE (3,202) (AL(I),I=1,4),AA,BB
204 FORMAT ("LEVEL CHANGE 2-5 + TOT + AV='14X,6F13.2")
AA=0
DO 205 I=1,4
205 AA=AA+AV(I)
BB=AA/4.0
WRITE (3,204) (AV(I),I=1,4),AA,BB
206 FORMAT ("LEVEL RANGE 2-5 + ZAP + AV='15X,6F13.2")
207 FORMAT (" H A N D C A L C R A N G E P E R C E N T - H E I G H T")
AA=0
BB=0
208 DO 209 I=1,4
BB=BB+AV(I)/4*0
WRITE (3,209) (AV(I),I=1,4),AA,BB
WRITE (3,207)
209 FORMAT ("OPC PT POSSIBLE LOCATION SHIFTS 2-5, TOT, AV='1,6F13.2")
AA=0
DO 210 I=1,4
210 AA=AA+ALC(I)
BB=AA/4.0
WRITE (3,210) (ALC(I),I=1,4),AA,BB
211 FORMAT ("OPC PT ENTERABLE SO ENTERED 2-5, TOT, AV='1,6X,6F13.2")
AA=0
DO 212 I=1,4
AA=AA+AUL(I)
212 BB=AA/4.0
WRITE (3,212) (AUL(I),I=1,4),AA,BB
213 FORMAT ("OFLOOR PATTERN RANGE 2-5, ZAP, AV='1,9X,6F13.2,"0")
APPENDIX F (continued)

SOURCE LISTING OF COMPUTER PROGRAM

AA = 0
BH = 0
DO 214 I = 1,4
   214 BH = BH + FPRI(I)/4.0
WRITE (3,213) (FPRI(I),I = 1,4), AA,BH
GO TO 101
END

FEATURES SUPPORTED
NONPROCESS
ONE WORD INTEGERS
IUCS

CORE REQUIREMENTS FOR DUMMY
COMMON 0 INSKEI COMMON 0 VARIABLES 858 PROGRAM 1930

END OF COMPILATION
BIBLIOGRAPHY

Books


**Articles and Periodicals**


Dow, M. "Playground Behavior Differentiating Artistic from Non-Artistic Children." Psychology Monographs, XLV (1933), 82-94.


Kurath, Gertrude P. "A New Method of Choreographic Notation." American Anthropologist, III (1950), 120-123.

Laban, Juana de. "Introduction to Dance Notation." Dance Index, V (April, 1946), 89-132.


Pollenz, Philippa, "Methods for the Comparative Study of the Dance." 

Scripps, Louise E., "Brief Contributions: A System of Ethnic Dance 
Notation." Journal of the Society for Ethnomusicology, IX
(May, 1965), 145-156.

Swinton, R. S. "Analysis of Child Behavior by Intermittent Photo-
graphy." Child Development, V (1934), 292-293.

Walton, James, "A High Speed Timing Unit for Cinematography."

Unpublished Materials

Ahrens, Shirley J., "Spatial Dimensions of Movement." Unpublished 

Ahroni, Yael, "Analytical Study of the Anatomical Notation System." 
Unpublished Master's Thesis, University of Wisconsin, Madison, 
1968.

Anderson, Cynthia C., "A Method of Data Collection and Processing for 
Cinematographic Analysis of Human Movement in Three Dimensions." 
Unpublished Master's Thesis, University of Wisconsin, Madison, 
1970.

Atwater, Anne E., "Movement Characteristics of the Overarm Throw: 
A Kinematic Analysis of Men and Women Performers." Unpublished 

Chrietzberg, Agnes L., "The Relationship Between Maternal Guidance 
During Motor Performance and the Motor Skill of Preschool 
University, 1969.

Craighead, "A System of Notation for the Modern Dance." Unpublished 
Master's Thesis, University of Louisiana, 1942.

Cross, Gertrude, "A System of Notation for Recording Dance." 

Dyke, Jennie, "Dance Notation: A Comparative Analysis and Evaluation 
College, 1939.


Hunt, Valerie V., Unpublished material presented in Graduate Seminar, Human Movement, University of California, Los Angeles, Fall Term, 1964.


