Cognitive Structures of Kinesthetic Space
Reevaluating Rudolf Laban's Choreutics
In the Context of Spatial Cognition and Motor Control

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Submitted for the Degree of
Doctor of Philosophy

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September, 1996

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Abstract

The choreutic conception of the spatial aspect of body movements (originated by Rudolf Laban) was reevaluated according to cognitive and motor control research.

"Kinesthetic spatial cognition" (analogous to visual spatial cognition) was identified as the psychological realm of choreutic knowledge. Kinesthesia was identified as arising from sensory receptors throughout the body. Kinesthetic space was defined as spatial information derived from kinesthesia. Kinesthetic spatial cognition was defined as cognitive processes (eg. mental rehearsal) involving kinesthetic spatial knowledge. This concept of kinesthetic spatial cognition has not been heretofore explicitly developed in cognitive science.

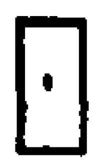
Elements of the choreutic conception were psychologically validated since they are also well identified in cognitive and motor research. These include how spatial information is defined relative to a reference system; kinesthetic spatial knowledge is based on a mental code of elemental locations; higher-order networks of locations are collected into map-like spatial images; and many symmetrical operations can be performed. Close similarities were identified between choreutic polyhedral-shaped cognitive maps of the "kinesphere" and the "trajectory formation" model.

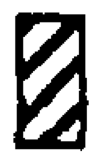
A choreutic prototype/deflection hypothesis posits that dimensions and diagonals serve as conceptual prototypes while actual body movement consists of deflections. Similar spatial prototypes were identified in visual spatial cognition, a kinesiological analysis supported the bodily tendency towards deflections, and this concurred with ergonomic measurements of the shape of the workspace. An experiment attempted to identify prototypes in kinesthetic spatial cognition.

Categories of kinesthetic spatial information are distinguished within choreutics and dance. These were reevaluated according to perceptual processes and kinesiology. Choreutic topological forms deflecting across various kinespheric nets are analogous to N. Bernstein's conception of the "co-ordinational net of the motor field . . . as oscillating like a cobweb in the wind". An experiment demonstrated that kinesthetic spatial information is organised into cognitive categories and that choreutic material and Labanotation symbols can be advantageously used in experimental research.

Key to Labanotation Direction Symbols

The Labanotation* direction symbols are used within this thesis. They refer to spatial directions as listed here. For further details see Hutchinson (1970), Hutchinson-Guest (1983), Knust (1979a; 1979b), Laban (1975b), and Preston-Dunlop (1969). The direction symbols are also discussed in Section IVA of this thesis.

 Centre

 Vertically upwards

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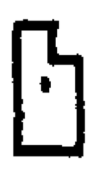 Sagittally forwards

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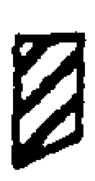 Up-left-backwards

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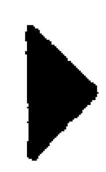 Down-rightwards

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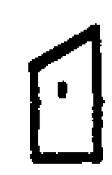
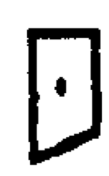
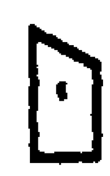
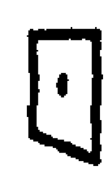
 Right-forwards

 Left-backwards

 Left-forwards

 Right-backwards

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* Laban originally named this system of movement notation "kinetography" (Knust, 1948a, p. 28), literally "movement-writing". Other systems of dance/movement notation or kinetography have also been developed (for a review see Hutchinson-Guest, 1989). In order to distinguish Laban's system it has been referred to as "Laban Kinetography" (Knust, 1948a, 1948b), "kinetography Laban" (Preston-Dunlop, 1969), "Laban Notation" (Laban, 1948, p. 6), or as either "kinetography Laban" or "Labanotation" (Hutchinson, 1970; Knust, 1979a; 1979b). There are some differences between European Kinetography-Laban and American Labanotation, but these are not critical to this thesis. The term "Labanotation" is used here to refer generally to the overall system of body-movement-notation originated by R. Laban and of which the direction symbols are still at the core.

APPENDIX I

RESEARCH PROPOSAL AND TRANSFER OF REGISTRATION TO PH.D.

The original research proposal (Longstaff, 1990) and the transfer of registration from master of philosophy to doctor of philosophy (Longstaff, 1992) are presented here (not including footnotes). These reveal the gradual refinement of focus which occurred during the course of this research.

APX. I.10 Application to Register for

Council for National Academic Award's Research Degree

APX. I.11 Overview of Original Research Proposal.

The original research proposal (Longstaff, 1990) was focused toward choreutic education. The plan was to define the content of choreutic knowledge, identify the problems in communicating this knowledge, and determine the best ways to teach this knowledge to students. This was to be supported by cognitive psychological studies of spatial perception which appeared to address issues in choreutic knowledge acquisition.

APX. I.12 Original "Title of the Proposed Investigation".

Techniques for Choreutic Education in Dance:

Translating Three-dimensional Perception into

Kinetic Spatial Imagination

APX. I.13 Original "Aim of the Investigation" (actual text).

The aim of this research is to discern problems, and to design and test techniques, of effective choreutic education for adults in the field of dance.

APX. I.14 Original "Proposed Plan of Work . . ." (actual text).

Choreutics is an architectural and polyhedral system for conceiving and executing spatial movement forms. Laban (1926; 1966; 1984), Ullmann (1966; 1971), Bartenieff and Lewis (1980), Dell (1972), Bodmer (1979), Preston-Dunlop (1980; 1978; 1981; 1984) and Salter (1977) introduce choreutic elements. Beyond these elements, the "choreutic laws" (Laban, 1966, p. 26) are only alluded to in dispersed statements and never presented as an integrated whole. Difficulties for choreutic education are in the visual representations of three-dimensional form, and [inevitably incomplete] attempts at two-dimensional conceptual analysis. Closer research (Longstaff, 1986; 1987; 1989) reveals choreutics' intricate systematic spatial conception based on patterns of equilibrium reflexes (Laban, 1966, p. 89) and physics of "stable and labile"

(Ullmann, 1966, pp. 199-207) use of body-weight in relation to gravity.

During the first and second year I will undertake supportive course work* towards discerning issues and methods of perceiving and teaching three-dimensional spatial awareness and bodily kinetics. I will also use polyhedral geometric methods developed out of my M. S. Thesis (Longstaff, 1989), to analyse the theoretic choreutic three-dimensional structural and infrastructural relationships.

During the second and third year I plan to conduct observations of dancers performing choreutic based movement phrases and analyse their spontaneous performance relationships of deviations and clusters. I expect patterns of performance relationships to practically inform the theoretic structural relationships and reveal the harmonic movement principles as spontaneous bodily organisations of spatial shapes identifiable within a hierarchy of choreutic form. This should provide deeper insight into the content of the choreutic knowledge to be taught.

During the third and fourth year I intend to apply knowledge of perceptual and educational processes towards developing techniques for teaching choreutic three-dimensional perception and kinetic imagination. I expect that these will address the multi-sensory nature of perceptual systems. I will then test the techniques through experimental choreutic workshops designed to collect reliable and valid data regarding degrees of students' acquisition of choreutic knowledge. The results should give indications of which educational techniques are most effective.

The thesis will take the form of 1) a written document which discusses the data and results of the research, including a video-tape of the analysed movement phrases and experimental choreutic workshops, and 2) a video-tape implementing the effective techniques for choreutic education.

APX. I.20 Application For Transfer of Registration from Master of Philosophy to Doctor of Philosophy

APX. I.21 Overview of Transfer of Registration.

The application for transfer of registration from master of philosophy to doctor of philosophy (Longstaff, 1992) contained a change of title and identified a refined focus in the research. During the course of the research it was found that

* Supportive courses included the M. A. course in Choreological studies (Laban Centre), the M. A. course in Education in Dance (Laban Centre), and a psychology course in Information Processing and Cognition (Goldsmiths' College).

issues of spatial perception and cognition were so broad and complex that simply identifying these could comprise an entire thesis and constitute significant new knowledge. Thus, the refined focus of the research became the identification of the nature and content of choreutic knowledge according to similar well developed concepts in the fields of cognitive psychology and motor control.

APX. I.22 Revised Title of the Research.

Cognitive Structures of Kinesthetic-Space:

Integrating Choreutic Concepts in Dance with Characteristics of

Spatial Cognition from Cognitive Psychology and Motor Control

APX. I.23 Progress Report for Transfer of Registration (actual text).

The first stage of this research has consisted of acquiring a foundation of preliminary knowledge within two subject areas: Choreutic concepts as studied within the field of dance, and; Spatial perception, memory and retrieval as studied within the fields of cognitive psychology and motor control.

Choreutics is the term fostered by Laban to refer to the spatial organisation of bodily movements (Laban, 1966, pp. vii-ix) and so is synonymous with the perceptual concept of "kinesthetic-space". Choreutic concepts have been used to describe spatial movement behaviour within diverse fields. Any type of movement which is based on a spatial concept can be referred to as "choreutic". This present study focuses on reviewing choreutic concepts within the field of dance. A programme of choreutic studies was completed [see note above], independent research culminated in three papers# which review the scope of choreutic concepts and two additional papers are also currently underway.

Spatial perception studies were completed [see note above] and a review of spatial cognition in the fields of cognitive psychology and motor control culminated in a paper titled "spatial perception".+ This review examines the sensation, perception,

\# The papers included "Elements of Bodily Spatial Form" (85 pp.) which derives a taxonomy of forms producible by the human body; "Kinesphere and Dynamosphere, Trace-forms and Shadow-forms, and Affinities" (114 pp.) which reviews these concepts that are central to choreutic knowledge, and; "Annotations and Analyses of Choreographie" which consists of an analysis of the early development of choreutics within Laban's (1926) German work; originally translated by J. Dunlop and V. Preston-Dunlop, then re-translated to a more literal version by myself and E. Zierach.

\+ This paper was later, more accurately, titled "Spatial Cognition" (162 pp.) and includes discussion of visual, audio, and kinesthetic sensory processes; models of cognitive processing of sensory information; separable spatial versus verbal information-types; and mental representations in memory structures.

memory storage, and retrieval of spatial information.

This preliminary research reveals that spatial cognitive structures are biased towards visual perception and that there is a lack of verified knowledge about kinesthetic spatial cognitive structures (eg. choreutics) by dance theorists. This gap in the present knowledge can potentially be filled by integrating the characteristics of spatial cognition with choreutic conceptions in dance. This can provide psychological validity for the conceptual organisations of kinesthetic space in dance.

This integration has already been begun. Choreutic conceptions are cognitively assessed within the papers cited above. Experimental paradigms* are developed to probe the structure of kinesthetic-spatial cognition. A first experiment has been undertaken and further experiments are planned for the next year.#

The aim towards choreutic education of the original research proposal [see above] led to a preliminary study of spatial cognition in order to determine educational issues and as a result the original aim has been refined. Rather than focusing on the transfer of knowledge in education, this revised aim focuses on evaluating the nature of the knowledge by integrating the psychological study of spatial cognition with the dance study of choreutics. This revised aim of the research into the structures of kinesthetic spatial cognition is a unique and complex research project in itself. Educational issues continue to be implicitly addressed within this refined research aim. The eventual research findings are intended to inform the practical activity of choreutic education.

As a consequence of the refined aim of this research a new title is proposed which more precisely exhibits the content of the actual research.

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* A paper "Paradigms for Research in Dance" (30 pp.) outlines possible experimental research designs which can be applied to the study of kinesthetic-spatial perception, memory and recall.

\# The experiment "Subjective Organisation in Kinesthetic Recall" had been completed and identified how subjects spontaneously organise kinesthetic-items (ie. movements) into categories (see IVB.50). An experiment was planned to probe memory for kinesthetic-space in the same ways and memory for large-scale spaces known as "cognitive maps". This was later titled "Probing for Kinespheric Reference Points" and attempted (unsuccessfully) to identify reference points within the mental representation of the kinesphere (see IVA.90).

APPENDIX II

KINESTHESIA

APX. II.10 Variety of Terms

A variety of terms, including kinesthesia, proprioception, somaesthesia, the haptic system, position sense, muscle sense, joint sense, and movement sense, have all been used in similar ways to describe aspects of the perception of bodily movements and positions.

APX. II.11 Sixth sense.

The sense of bodily movement and position of one's own body does not fit easily into Aristotle's classic senses; seeing, hearing, smelling, tasting, and touching. Consequently Sir Charles Bell (1833) and others more recently (Fitt, 1988, p. 266) use the notion of a "sixth sense".

Dickinson (1974, p. 9) explains how the five senses were based on a "doctrine of 'specific nerve energies'" whereby a particular sense is thought to emerge from a particular sensory receptor. This has been shown to generally not hold true. For example, audition and vision both utilise data from head and body movements which are used to achieve a variety of postural orientations from which to sample the visual or audio stimuli (Scharf and Houtsma 1986; Sedgwick 1986). This is especially true for the perception of bodily movements and positions which arises from receptors throughout the body, including muscles, joints, tendons, skin, labyrinth, visual, audio, and an efferent discharge loop (see below):

> . . . the doctrine of 'specific nerve energies' [which was] held earlier this century has blinded later researchers to the fact that movement sensitivity does not depend on specialized receptors. It is not simply a sixth sense to be added to Aristotle's five classical senses. (Dickinson, 1974, p. 9)

APX. II.12 Touch.

The sense of bodily movement and position can also be conceived to be an expanded generalised version of Aristotle's sense of touch. Bastian (1888, p. 5), who proposed the term "kinesthesia" (see below) noted that its "cerebral seat or area corresponds with the sense of touch". Rock and Harris (1967, p. 96) also use "touch in this broad definition" according to which "Touch includes several other components [in addition to skin sensitivity], of which the one most significant for this discussion is the position sense".

Indeed, the sense of touch, or cutaneous sense, is itself not entirely based on data from skin receptors but also relies on sensations from muscles, tendons, and joints to perceive the shapes of objects being touched by moving the body around the object, and to perceive the texture of an object by exerting variations in pressure (Gibson, 1966, pp. 50, 53; Schwartz et al., 1975).

The sensations of bodily movements, positions, and touch, all arise from the same system of receptors and so they can be conceived to belong to the same sensory system. The specialised "touch" sub-system can be included together with the other specialised kinesthetic sub-systems including the sense of balance, force, linear or rotary self-motion, sense of limb movement and limb position (see below).

APX. II.13 Kinesthesia.

Bastian (1888) proposed the term "kinesthesis" to refer to the "sensations which result from or are directly occasioned by movements" (p. 5). Despite its etymology (Greek *kinein*, to move + *aisthesis*, feeling; American, 1982]) meaning literally "the feeling of movement", this term was intended to replace both the terms "'muscular sense,' and 'sense of force'" which were previously in use (p. 5). Thus, under the heading of kinesthesis he included the perception of "position and movements of our limbs", and "different degrees of 'resistance' and 'weight'" (p. 6). The dictionary definition of kinesthesia also groups together the various sub-senses within its class, including "bodily position, weight, muscle tension, and movement" (Collins, 1986) and also the sense of "presence" (American, 1982).

The term "muscle sense" may be synonymous with kinesthesia (Collins, 1986) in that "kinesthesia" was adopted to replace the former term (Clark and Horch, 1986). Alternatively, the muscle sense may be considered to be one of the several kinesthetic sub-senses, including "muscle sense" (receptors in muscles), "tendon sense" (receptors in tendons), "joint sense" (receptors in skeletal joints), and "static sense" (receptors in the labyrinth) (English and English, 1974).

The common accepted usage is that kinesthesia refers to the perception of ones own bodily movements and positions (Fitt, 1988, p. 266), and sometimes also the forces produced or reacted to (Rasch and Burke, 1978, p. 80). Some authors also include processes of "motor coordination" and "motor memory" as part of kinesthesia (Fitt, 1988, p. 267).

In contrast, Cross and McCloskey (1973, p. 443) distinguish between "position sense" for limb positions and "kinesthetic sensations" for limb movement. McCloskey (1973) vibrated the tendon of subjects' biceps brachii muscle with a physiotherapy vibrator which induced the subject to perceive an illusion of movement at the elbow joint. The illusions of movement and illusions of position were able to be experimentally manipulated so that they did not correspond: A longer duration movement illusion did not result in different position illusions; A low frequency vibration did not cause a movement illusion but did create an illusion of a changed position:

> . . . subjective judgements of the static positions of joints and judgements of movements of joints can use different lines of information. It is suggested that the term 'position sense' be reserved for the static judgements, and 'kinesthesia' for the dynamic ones, and that the two terms should not be regarded as synonymous. (McCloskey, 1973, p. 130)

APX. II.14 Proprioception.

Sherrington (1906) uses the term "proprioception" in his discussion of how types of sensory impulses will initiate certain physical reflexes. Sherrington draws a general distinction between internally versus externally produced sensory stimulations:

> Multicellular animals . . . are cellular masses presenting to the environment a surface sheet of cells, and under that [is] a cellular bulk [which is] more or less screened from the environment by the surface sheet. (Sherrington, 1906, p. 316)

"Proprioceptors" refer to the receptor cells which are screened from the exterior environment, and so "the stimuli to the receptors are given by the organism itself" (Sherrington, 1906, p. 130). The term derives from the Latin *proprius* (one's own) plus "reception" and so is defined as "the reception of stimuli arising within the organism" (American, 1982).

Sherrington (1906) distinguishes two types of sensory cells on the organism's exterior surface; exteroceptors and interoceptors. "Exteroceptors" refer to sensory cells which are "freely open to the numberless vicissitudes and agencies of the environment" (p. 317). "Interoceptors" refer to sensory cells on "surfaces" of the body, but which have developed deep recessions, "in this recess a fraction of the environment is more or less surrounded by the organism" (p. 317).

Vestibular "labyrinth" receptors form a special case. Sherrington (1906, p. 336) describes these as being "derived from the extero-ceptive, but later recessed off from it" and which now function as proprioceptors:

> The proprio-ceptors of the body generally and of the labyrinth receptors in the head appear to co-operate together and form functionally one receptive system ... embraced within the term "proprio-ceptive". (Sherrington, 1906, p. 341)

Sherrington distinguishes the following groups of sensory receptors:

Proprioceptors found in:	muscles, joints, tendons, labyrinth.
Exteroceptors found in:	eyes, ears, skin.
Interoceptors found in:	mouth, stomach, nose.

Sherrington's distinctions are often followed closely (Dickinson, 1974, p. 10; Ellison, 1993, p. 75; Rock, 1968) and also have been misrepresented. For example Wells and Luttgens (1976, p. 58) consider proprioceptors (together with visceroceptors) to be a type of interoceptor, contrary to Sherrington who explicitly distinguishes between the two.

APX. II.15 Somaesthesia.

"Somaesthesia" (or, somesthesis, somatosensory) is used very similar to proprioception in that they both refer to perceptions arising out of one own's body (from Greek *soma*, the body). Somaesthesia refers to sensations of body movements and positions, and also to sensations of temperature, pressure, touch, and pain (Collins, 1986). It is generally used to refer to stimulations arising from receptors in muscles, tendons, joints and skin (not vestibular) (Bles, 1981; Lackner and DiZio, 1984; Taub et al., 1973; 1975). The muscle/tendon/joint/skin conception of somaesthesia is sometimes considered to be synonymous with kinesthesis (English and English, 1974).

APX. II.16 Haptic system.

Gibson (1966, pp. 50, 53) proposed a sub-group within proprioception which he termed the "haptic system" with its "mode of attention" as "touching" and using sensory data from receptors in skin, joints, muscles, and tendons to produce perceptions about the environment or the body. The "hands and other body members" are considered to be the "organs of perception". The haptic system can derive information about one's own body or about the exterior environment (eg. feeling the shape of an object) and so is both proprioceptive and exteroceptive. "Haptic" is from the Greek *haptein*, to touch, (Collins, 1986) and so is identical with the generalised notion of the sense of touch (see above).

APX. II.20 Discussion and Working Definitions

This varied terminology describes perception of body movements and positions in slightly different ways. Certain criteria can be identified to asses the usefulness of each term.

APX. II.21 Invalidity of Internal / External Distinction.

The proprioceptive/exteroceptive distinction between internal stimuli from the body versus external stimuli from the environment has been found to be invalid. In many cases external stimuli such as visual-field motion or audio-field motion (see below) provide information about the body's movement. In his landmark work, Gibson (1966) explored how audio and visual perception are extremely important for the perception of one's own movements. It has been shown that the movement of audio or visual fields can easily induce illusions of self-motion even in the absence of joint, muscle, tendon and labyrinth stimulations (G. J. Anderson, 1986; see below). This type of external stimulation is also vital for maintenance of the body's balance (Lee and Aronson, 1974; see below).

Thus, in addition to the traditional "muscular proprioception" (muscle receptors), "articular proprioception" (joint receptors), and "vestibular proprioception" (labyrinth), Gibson (1966, pp. 36-37) also includes "cutaneous proprioception" (skin receptors), "auditory proprioception", and "visual proprioception". Other researchers also use the terms "visual proprioception" (Lee and Aronson, 1974; Lee and Lishman, 1975), "visual kinesthesis" (Lishman and Lee, 1973; Rieger, 1983; Warren et al., 1988, p. 646), "visuopostural feedback" (Souder, 1972, p. 15), and "exproprioception", literally, perceiving the inside from the outside (Fitch et al., 1982, pp. 275-276; D. N. Lee, 1978). Receptors in skin which can receive stimulation from the exterior environment will also respond to stimulations from body movement. Thus these must be classified as both proprioceptors and exteroceptors. Bastian (1888), who proposed the term "kinesthesia" stated this same fact at the outset, that "the group of sensations under the name of kinaesthesis . . . is confessedly a mixed group partly 'intrinsic' and partly 'extrinsic' in their origin" (p. 6).

APX. II.22 Inconsistent use of "Kinesthesia" versus "Proprioception".

Another problem is that the terms "kinesthesia" and "proprioception" are not consistently defined. Typically the two terms are used synonymously (Clark and Horch, 1986; Schmidt, 1982, p. 202) and Moberg (1983, p. 1) considers "kinesthetic sensibility, position sense, muscle sense or proprioception" as synonyms. Similarly, sometimes the term "visual proprioception"(Lee and Aronson, 1974; Lee and Lishman, 1975), is used, while others refer to this as "visual kinesthesis" (Lishman and Lee, 1973; Rieger, 1983; Warren et al., 1988, p. 646).

The particular components included within kinesthesis or proprioception also vary among authors. In the narrowest view stimulations arising from receptors in muscles, tendons, and joints (not labyrinth or skin) are included as proprioceptors (Fitt, 1988, p. 266) or as kinesthetic (Laszlo and Bairstow, 1971).

In a slightly broader view, Bastian (1888, p. 5) considered receptors in muscles, tendons, joints and skin (but not vestibular) as being kinesthetic. Perhaps vestibular was not included because Bastian focused on the positions and movements "of our limbs" (p. 6) rather than linear or rotary self-motion (see below). Other writers also follow this same view of including stimulations from muscle, joint, tendon, and skin (but not vestibular) receptors as being kinesthetic (Clark and Horch, 1986) or as proprioceptive (Rothwell, 1987, p. 74), or as proprioceptive considered synonymous with somatic sensation (Taub and Berman, 1968). Similarly, Souder (1972, p. 14) considers the vestibular labyrinth to be a separate system from either kinesthetic or proprioceptive. Sherrick and Cholewaik (1986, p. 111-3) consider the cutaneous sense to be exteroceptive but also that "the senses of the skin do occasional duty as supplement to the kinesthetic senses". Wells and Luttgens (1976, pp. 58-61) include skin receptors as being proprioceptive only when they participate in withdraw and thrust reflexes.

Other authors use Sherrington's (1906) original distinctions of including sensations arising from muscle, tendon, joint, and labyrinth (but not skin) receptors within proprioception (Dickinson, 1974; Ellison, 1993, p. 75; Rock, 1968).

In the broadest view, visual, audio, skin and labyrinth receptors are included together with receptors in muscles, tendons and joints as all contributing to kinesthesia (Rasch and Burke, 1978, pp. 80-81), or to proprioception (Gibson, 1966, pp. 36-37), or as kinesthesia considered synonymous with proprioception (Schmidt, 1982, chapter 6):

> Historically, kinesthesis . . . was a term limited to a person's perception of his or her own motion, both of the limbs with respect to one another, and also of the body as a whole. Sherrington's (1906) term *proprioception* was originally used to mean the perception of movement of the body plus its orientation in space (even though it may not be moving). Over the years these two terms have become practically synonymous, and it is probably not important to continue this distinction. (Schmidt, 1982, p. 202)

Other researchers might arrange kinesthesia and proprioception into a kind of hierarchy, however these arrangements tend to vary. The proprioceptive system is sometimes considered as a higher-order system containing the separate kinesthetic and vestibular systems (Riesser and Pick, 1976; Sherrick and Cholewaik, 1986). Strelow and Babyn (1981, p. 191) list "vestibular, kinaesthetic, and proprioceptive information" implying that the three are separate. Singleton (1972, p. 61) represents the somaesthetic system as containing the proprioceptive system and the tactile system. The proprioceptive system is then further subdivided as containing the kinesthetic system (including receptions from muscles, tendons, and joints) which is separate from the vestibular system.

APX. II.23 Kinesthesia and Proprioception as Conscious and Unconscious .

Kinesthesia is sometimes used to refer to conscious perceptions since the Greek root *aesthesia* means "to perceive", while proprioception is not necessarily conscious but may occur as unconscious sensory receptions which elicit reflex reactions. This conception places kinesthesia as a higher-order derivative which calls on proprioception for its data.

Much of Sherrington's (1906) research which distinguished the term "proprioception" focused on reflex actions produced when stimulating particular receptors. McCloskey (1978, p. 764) also describes that Sherrington used proprioception to refer to "vestibular sensations and inputs from muscles and joints that are not necessarily perceived" and other authors explicitly refer to the conscious/unconscious distinction between kinesthesia and proprioception (Ellison, 1993, p. 75; Paillard and Brouchon, 1974, p. 275). Correspondingly, in Lee and Lishman's studies of vision and body movement, they use "visual kinaesthesia" (Lishman and Lee, 1973) when they are studying subjects' conscious perceptions of their own self-motion, whereas they use "visual proprioception" (Lee and Lishman, 1975) when they are studying subjects' unconscious, reflexive responses for maintaining upright posture.

Research has also focused on whether sensory discharges from muscle spindle receptors have any direct access to conscious perception (kinesthesia) or are used solely for subconscious reflexive control of movement (proprioception). This question has been referred to as the "problem of 'conscious proprioception,' whether there is awareness of muscle length and tension changes" (Gelfan and Carter, 1967).

Some evidence indicates that sensory reception from muscles is not consciously perceived. Anaesthestized joints produces a loss of perception of passive movement or position in the finger joint (Provins, 1958) or the toe (Browne et al., 1954) even though the muscles which act upon these joints were unaffected by the anaesthesia. Stretching a muscle by pulling on the exposed tendon does not produce any conscious perception of limb movement in the fingers, hand, or foot and so Gelfan and Carter (1967) conclude that "there is no muscle sense in man". This effect was duplicated by Moberg (1983) who stresses the importance of skin receptors (rather than joint or muscle receptors) for conscious kinesthesia in the fingers and hand.

However other evidence indicates that muscles do play a role in conscious perception. Sensory impulses from muscle spindle receptors have been found to have direct connections to the cerebral cortex in baboons (Phillips et al., 1971) and cats (Oscarsson and Rosen, 1963). When muscles acting on the fingers are lightly tensed or voluntarily moved then motion is perceived even if the joints and skin have been paralysed (Goodwin et al., 1972a; 1972b). This sensory facilitation of actively moved versus passively manipulated muscles was also noted earlier (Browne et al., 1954). Illusions of forearm movements and false positions have also been elicited by vibrating the muscles and tendons with a physiotherapy vibrator (Goodwin et al., 1972a; 1972c).

Distinguishing receptors as to whether their stimulations become conscious or unconscious appears to be a tentative affair. This is especially true since conscious perceptions rarely arise solely from the sensations of one individual receptor, especially in kinesthesia where input from an abundance of receptors is combined into a unified perception. Conscious kinesthesia is not attributed to particular receptors per se, but as a phenomenological experience of the body's positions, motions, forces etc. In McCloskey's (1978) exhaustive review of "kinesthetic sensibility", and in particular the question of "Are muscles sentient?", it is noted that "perceptions" are not experienced in the receptors, but in the objects perceived:

> . . . we are no more likely to feel kinesthetic sensations *in* our muscles or joints than we are to hear sounds *in* our heads or see objects *in* our retinas - but [conscious kinesthesia] would be sensations of movement, or force, or tension, or of altered position in the parts moved *by* the muscles. (McCloskey, 1978, p. 777 [italics his])

It would not be beneficial for the raw data from receptors to be available to consciousness since the data from collections of receptors must be interpreted relative to each other and to exterior forces (gravity, momentum, external objects) and relative to any motor commands which have been executed. These will all influence the significance of any isolated receptor response:

> . . . the essential point is that it would be of little value for the highest sensory centres to receive raw data from the muscle afferents, because what these mean depends entirely upon what the relevant muscle is being told to do by the motor system. (Goodwin et al., 1972a, p. 744)

Likewise, in a study of the history of proprioception Dickinson (1974, p. 10) concludes that "at a physiological level, the absence of a direct link from receptors to the cortex may not necessarily preclude some indirect participation in perception" since the perception is derived at an unconscious level anyway.

APX. II.24 Conclusions: Working Definitions.

From the overlapping concepts of somaesthesia, kinesthesia, proprioception, etc. outlined above, the following working definitions will be used in this study.

The term "proprioception" will not be used since it belongs to an interior/exterior distinction which has been shown to be invalid. In Dickinson's (1974) historical review of proprioception it is observed that "Not only is there disagreement concerning the definition of proprioception, there is even disagreement over whether proprioception may be viewed as a sensory modality" (p. 9). Clark and Horch (1986, p. 13.2) state that "the term proprioceptive lacks a precise definition" and therefore they prefer the term kinesthesia. In light of the other terms available, the notion of proprioception is not necessary.

Kinesthesia will be used in its broadest sense to refer to perceptions arising from muscle, tendon, joint, skin, vestibular, visual, and audio receptors. In addition, an interior knowledge of motor commands or "efferent data" can be considered to be another source of kinesthetic information (see below).

Other "senses" can be classified as kinesthetic sub-systems. These include limb position sense, limb movement sense, sense of linear or rotary self-motion, sense of balance or equilibrium, and the sense of force.

"Somatic" will be used in its typical definition of referring to perceptions arising from receptors in muscles, tendons, joints, and skin. These receptors comprise a complete grouping in themselves within the larger group of kinesthetic receptors. This somatic system is synonymous with the haptic system but since "haptic" comes from "to touch" it is more related to skin receptors. Somatic is chosen here since it refers to perceptions from anywhere in the body.

APX. II.30 Types of Kinesthetic Raw Data

Various sensory receptors and an internal knowledge of motor commands contribute data which is derived into kinesthetic perceptions. This section will briefly review the functioning of each type of receptor, the stimulation which it responds to, and the type(s) of information the receptors provide. Evidence for an internal knowledge of motor commands (referred to here as "efferent data") is also noted.

A fundamental characteristic of receptor function is the rate of "adaptation" of a sensory receptor response to a stimulus which is steady and continual (Sherrick and Cholewaik, 1986, p. 111-6). These are classified as generally two types: 1) Quickly adapting receptors stop responding to a continual stimulus very soon are are therefore efficient in sensing rapidly changing stimulations such as quick movements; 2) Slowly adapting receptors maintain their response to a continual stimulus for a long period and are therefore efficient in sensing continuous, unchanging stimulations such as a maintained bodily position.

APX. II.31 Muscle Spindles: Primary and Secondary Endings.

Muscles are composed of hundreds of individual long slender muscle fibres which connect to tendon filaments at either end which in turn attach to bones. The large main muscle fibres are referred to as extrafusal fibres and produce the muscle's strength from their force of contraction.

Modified muscle fibres of the sensory spindle organs are referred to as intrafusal fibers and are arranged in parallel to the longer, thicker extrafusal fibres. This arrangement allows the intrafusal fibres to shorten and lengthen together with the extrafusal fibres but without carrying any of the burden of force. A muscle spindle receptor, within the thin intrafusal fibres, has two types of sensory endings known as primary and secondary.

Secondary spindle endings increase their response linearly as the muscle length increases throughout the range of the muscle (Matthews and Stein, 1969) and so they function analogously to slowly adapting receptors. The secondary spindles provide data about the overall length of the muscle but are not sensitive to small quick changes in the muscle length (Rothwell, 1987, pp. 76-87).

Primary spindle endings are sensitive to much smaller muscle length increases but their response does not increase regularly with muscle length (Matthews and Stein, 1969). Rothwell (1987, pp. 77-79, 86-87, 97) reviews how primary endings are thought to respond to "cross-bridges" which link parallel intrafusal fibres. The cross-bridges are stiff, when the fibres slide apart (as the muscle lengthens) beyond some critical point the cross-bridges break and reform at the new muscle length. Because of this they are sensitive to very small changes in muscle length (motion) and then quickly return to a static level of response once the new length is arrived at. This pattern of response occurs irrespective of the overall muscle length. They are so sensitive to muscle length changes that they may even respond to arterial pulse or respiratory movements. However, the response of the primary endings to static positions is low, "only 10 per cent of spindles show any discharge at all at a comfortable rest position of the hand" (p. 97). This behaviour of quick responses to small stimuli changes, followed with an immediate return to a neutral response level is analogous with quickly adapting receptors.

From these patterns of responses, it is believed that the primary endings sense velocity of muscle change-of-length and muscle length, while the secondary endings sense only muscle length (Clark and Horch, 1986; Rothwell, 1987, pp. 74-104).

APX. II.32 Tendon Receptors.

Slowly adapting Golgi tendon organs are located at muscle-tendon junctions and are composed of a capsule enclosing several tendon filaments. These are attached end-to-end with muscle fibres and tendon filaments (in series) and this arrangement allows the Golgi tendon organs to respond to muscle-tendon tension regardless of muscle length. Muscle length and tension are separate, for example in an isometric contraction the muscles contract (increased muscle-tension) but limbs do not move (identical muscle-length). Golgi tendon organs have been shown to increase their response to increases in muscle tension very accurately (Crago et al., 1982).

Two other types of receptors in muscles and tendons seem to be of a lesser importance and have not been widely studied. Paciniform corpuscles are mostly found near the Golgi tendon organs are are sensitive to vibrations. Free nerve endings are found throughout the muscle and tendon structures and seem to be sensitive to mechanical pressure and pain stimulations (Clark and Horch, 1986; Rothwell, 1987, pp. 74-104).

APX. II.33 Joint receptors.

Slow adapting Golgi sensory receptors (similar to Golgi tendon organs), are found in the ligaments which connect bone to bone and form the outer layer of the joint capsule. Slow adapting Ruffini receptors and quick adapting paciniform corpuscles, similar to those found in skin, are also found in the tendon material of the joint capsule. Free nerve endings are found throughout the joint connective tissue (McCloskey, 1978, pp. 766-767).

The functioning of joint receptors is debated by physiologists (for reviews see Clark and Horch, 1986; and McCloskey, 1978). Skoglund's (1956) findings that cat knee joint receptors are selectively activated by certain positions of joint angle led most researchers to believe that the slow adapting Golgi and Ruffini receptors within the ligaments around the joint respond to being stretched. Contrary to this other researchers (Burgess and Clark, 1969; Clark, 1975; Clark and Burgess, 1975; Grigg, 1975) found that most cat knee joint receptors respond only to extreme joint angles. Still other researchers (Carli et al., 1979) found that cat hip joint receptors responded at all angles with the same increasing rate of response with increased flexion *or* extension of the joint.

The cat knee has also been shown to respond sensitively to pressure into the joint capsule, leading some researchers (Clark, 1975; Clark and Burgess, 1975) to hypothesize a pressure response (rather than a stretch response) for joint receptors. The quickly adapting paciniform corpuscles probably respond to high speed vibrations as they do in the skin. (General references for joint receptors; Clark and Horch, 1986; Rothwell, 1987, pp. 74-104.)

APX. II.34 Skin Receptors.

Free nerve endings are close to hair follicles and stimulated by movements of bodily hairs (resulting from bodily moves or external forces). Slow adapting Merkel disks are close to the surface of the skin, respond only to vertical skin pressure (ie.

pressure into the body, not lateral stretch of the skin), and may maintain their response to a constant pressure for up to ten minutes. Quickly adapting Meissner corpuscles are also close to the surface of the skin and sensitive to pressure but will cease responding in seconds.

Slow adapting Ruffini sensory endings are deeper in the skin and demonstrate a directional specific response to stretching of the skin. One direction of stretch will elicit a response, but a stretch at a right angle to that direction will elicit no response (Knibestol, 1975). Quick adapting Pacinian corpuscles are also deep in the skin and respond to stimuli in an area "almost as large as the whole palm in some cases" (Rothwell, 1987, p. 99). Its sensory ending is surrounded by concentric rings which eliminate low frequency vibration and so they respond only to rapid vibrations. (General references for skin receptors; Clark and Horch, 1986; and Rothwell, 1987, pp. 74-104.)

Receptors in skin provide kinesthetic data about the stretching and bending of the skin during movement and within poses. Skin kinesthesia may be especially important in areas of dense skin receptor populations such as the hands, feet, face, and mouth (Moberg, 1983; see below).

APX. II.35 Vestibular Receptors (Labyrinth).

The vestibular system is the non-auditory part of the inner ear. There is one vestibular system for each ear (bilateral). Each system is composed of two parts, the otolith organs and the semi-circular canals. Both the otolith organs and the canals consist of chambers filled with a think "endolymph" fluid. When the head moves through space the inertia of the heavy endolymph fluid causes it to lag behind the movement and thus push against a gelatinous membrane connected to tiny hairs which are connected to nerve endings. When a steady velocity is reached the endolymph fluid stabilises in its chambers and so the sensory response stops. Because of this, the vestibular system responds to accelerating or decelerating changes in speed but not to constant speed.

The otolith organs consist of two sack-shaped chambers, the utricle and the saccule, each filled with endolymph fluid. The hairs connected to nerve fibres are arranged on the floor of the utricle and around the wall of the saccule. Because of this symmetrical arrangement of hairs a rotary acceleration around a vertical axis passing through the head causes opposing forces in the otoliths which cancel each other out and therefore cause no sensation. A linear acceleration through space will cause the endolymph to push unevenly on the hairs and elicit a sensory response. The nerves of the otolith organ also have a constant discharge which continually indicates the direction of gravity.

The semi-circular canals consist of three ring-shaped chambers, each forming a compete circuit of endolymph fluid approximately 3-4mm in diameter. The three canals are oriented at approximate 90° angles from each other so that one canal is roughly parallel to the frontal, medial, and horizontal planes of the body. This mutually perpendicular arrangement allows rotation around any axis to be registered in at least one of the canals, however there is little response from purely linear motion.

In each canal there is one cupula which is the gelatinous projection into the endolymph fluid which is connected to the sensory hairs. When the head undergoes a rotary acceleration the inertia of the heavy endolymph fluid causes it to lag behind the motion and push against the cupula which elicits the sensory response. If the rotary speed is constant after a short time the fluid will stabilise in the canals and the nerves will stop responding. If the motion is then abruptly decelerated the fluid will continue moving and push against the cupula in the opposite direction. This can cause the sensation of turning in the opposite direction accompanied by post rotary nystagmus (see below). (General references for vestibular receptors; Kapit and Elson, 1977; Howard, 1986.)

APX. II.36 Visual Receptors.

The visual-motor system plays an important part in kinesthesia by sensing visual field motion and vision of the body moving (general references; Hood and Finkelstein, 1986; Hallett, 1986; Westheimer, 1986).

Each eye is roughly spherical. At the front of the eye the cornea bulges forward which serves to gather electromagnetic light rays into itself and thus expand the visual field.* The light which is collected by the cornea passes through the adjustable opening of the pupil and into the oval shaped lens.

The retina is a layer of photo-sensitive sensory receptor cells covering the interior surface of the eye. There are two types of visual receptor cells,

* The visual field consists of the spatial range of electromagnetic radiation reaching the retina at any one moment. This is also known as the visual array or the optic array.

approximately 120 million rods and 6.5 million cones in each eye. Cones occur in high density in the central fovea region of the retina (more than 140,000 / mm^2), low density in the peripheral region of the retina (less than 10,000 / mm^2) and are sensitive to high intensity light (daylight brightness), colour vision, and fine detail. Rods occur in low density in the central fovea region (virtually 0), high density in the peripheral region of the retina (from 50,000-160,000 / mm^2) and are sensitive to low intensity light (night-light brightness).

The fovea is a small area on the retina which contains a high density of cone photoreceptors. This is the retinal location where visual stimuli can be seen in greatest detail and so is where visual images fall when a person fixates her vision on a point in space. The size of the fovea can encompass stimuli which fills approximately 0.5° of visual angle[#] , or about the same visual angle occupied by a view of the moon from earth (Westheimer, 1986, p. 4.6).

Monocular focus, also called accommodation, is accomplished by the ciliary muscle adjusting circumferential tension around the lens, thus allowing the lens to bend the light rays in variable amounts. This adjustment of the lens' shape takes approximately 0.6 sec. to complete. The lens' accommodation bends the diverging light rays and converges them onto the retina at the back of the eye. When diverging light rays from a single point in space are converged by the lens into a single point on the retina, than this point is in monocular focus.

Binocular focus, also called vergence, is the only type of eye movement when the eyes do not follow parallel pathways. To keep a stimulus in binocular focus (ie. its image falling on the fovea of each eye) the two eyes either rotate closer together or farther apart in response to a stimulus moving closer or farther from the observer respectively.

Two types of data can be distinguished which contribute to visual kinesthesia. These can be referred to as visual field motion and vision-of-the-body moving.

APX. II.36a Visual field motion.

Early analysis of kinesthesia from visual field motion (Gibson, 1958; 1966) discussed how the visual field will appear to move across the retina when an

Visual angle refers to the amount of space filled by an object within the visual field, measured in angular degrees with the angle's vertex at the centre of the eye (Sedgwick, 1986).

organism travels or turns through space. Patterns of visual field motion, or "optical flow" become associated with the self-motion which usually produces them. For example, when traveling forward the entire visual field will expand and appear to move past on the sides while the point traveled toward remains in the centre of the visual field while gradually becoming larger (G. J. Andersen, 1986; Gibson, 1966).

Other cues within the visual array will add to the details available about the visual field motion (Sedgwick, 1986). "Motion parallax" refers to how visual stimuli close to the observer move across the visual field faster than visual stimuli far from the observer. "Occlusion" refers to how visual stimuli farther from the observer will sometimes disappear behind visual stimuli closer to the observer.

Visual nystagmus will also occur when the visual field flows across the retina. This is a basic orienting reflex which helps stabilise the perception of the visual world when the head is in motion. There are two phases of nystagmus which alternate slow phase, fast phase, slow phase etc.

During the slow phase of nystagmus the eyes remain fixated on a location in the exterior environment while the head is in motion. Thus, in the slow phase the eyes are rotating in the head in the opposite direction as the rotation of the head. This stabilises the perception of the exterior environment while the body is in motion.

During the fast phase of nystagmus the eyes quickly catch-up with the head, re-centering the eye in its socket and fixating on a new location in the exterior environment. Thus, in the fast phase the eyes are rotating in the same direction as the head motion.

When the body turns around the vertical axis the visual field flows across the retina right-to-left (or vice versa) and "horizontal nystagmus" occurs with the eyes also moving right and left. When the body rotates around the lateral axis (eg. somersaults) the visual field flows across the retina top-to-bottom (or vice versa) and "vertical nystagmus" occurs with the eyes also rotating up and down (also called "doll's eye reflex"). When the body rotates around the sagittal axis (eg. cartwheels) the visual field rotates around the retina clockwise or counterclockwise and "torsional nystagmus" occurs with the eyes also torqueing clockwise or counterclockwise. (General reference for nystagmus; Hallett, 1986.)

The motor commands for the eye movements will effect the characteristics of the nystagmus. Focusing and fixating on objects in the visual field results in less frequent, higher speed and larger distance quick phases of nystagmus than non-focused staring (Honrubia et al., 1968). When the eyes have a visual fixation goal the sequence of motion is as follows:

> 1) The eyes begin moving 20 msec before the head begins moving.
> 2) The eyes reach the target before the head reaches the target.
> 3) The head completes its movement to the target while the eyes remain stable and fixated at the target via a compensatory reverse motion relative to the head.

When there is not a visual fixation goal for the eye movement (eg. in a dark room) then the eyes respond to, rather than guiding the movement. The sequence of motion is as follows:

> 1) The head begins moving while the eyes begin slow phase of nystagmus in the opposite direction, remaining stable in the environment.
> 2) The head continues moving while the eyes alternate slow and fast phases of nystagmus.
> 3) The head completes its movement to a new position.
> 4) The eyes catch-up to the head with the nystagmus fast phase.

This reveals how eye motion can function to guide the body movement or the eye motion can occur as a reflex response in reaction to body movement (Bizzi, 1974; Howard, 1986). In dance practice a similar technique is used known as "'spotting'" in which "the eyes [are] focused at a definite point" while the body is turning (Grant, 1982, p. 84):

> [Spotting] is a term given to the movement of the head and focusing of the eyes in pirouettes [and other turning movements] . . . In these turns the dancer chooses a spot in front and as the turn is made away from the spot, the head is the last to leave and the first to arrive as the body completes the turn. This rapid movement . . . prevents the dancer from becoming dizzy.
> (Grant, 1982, p. 113)

Though the description of spotting often focuses on the use of the head, spotting is essentially an eye fixation which is maintained until the last possible moment during a turn. Then the eyes lead the movement around the turn and back to the same fixation point. This helps stabilise the perception of the exterior environment.

Nystagmus elicited by visual field motion is referred to as optokinetic nystagmus but nystagmus can also be elicited by audio, vestibular, or somatic sensations. The occurrence of nystagmus from a variety of stimuli, and the accompanying perception of self-motion, adds to evidence for "sensory convergence" which posits that afferent signals from different sensory receptors converge together within the nervous system (Bles, 1981; DiZio and Lackner, 1986).

During vestibular nystagmus (vestibulo-ocular reflex) stimulation from the vestibular canals and otolith organs elicits visual nystagmus (even in the absence of visual stimuli). Extrinsic eye muscles and vestibular canals are directly linked. Electrical stimulation to each of the six vestibular canals excites one of the corresponding six eye muscles which is responsible for moving the eye in the same plane of orientation as that canal (Hallett, 1986, p. 10.13).

The quality of vestibular nystagmus, and so kinesthetic perception, depends on types of visual fixation which are used while the body is rotating. Focusing on, or imagining, stationary objects in the environment results in a nystagmus slow phase of equal velocity as head movement speed. Non-focus in darkness results in slower slow phase speed than head movement speed. An imagined focus on an object moving along with the subject (imagined visual tracking) results in even slower phase speed, and focusing on a real object moving along with the subject (eg. focusing on your hand in front of your face while turning) virtually eliminates vestibular nystagmus completely (Barr et al., 1976).

When a subject rotates at a constant velocity after about 20 seconds the vestibular fluid stabilises and therefore stops stimulating the nervous system. If there is no visual field motion (eg. eyes are closed) then the nystagmus may stop. If bodily rotation decelerates the vestibular fluid will keep moving and therefore stimulate the nervous system just as if the body was rotating in the opposite direction. This deceleration elicits post rotary nystagmus where the body may have stopped turning yet the visual field appears to be rotating and nystagmus is occurring. The direction of this nystagmus may reverse several times while the vestibular fluid is gradually stabilising. Similar effects may be caused by alcohol consumption (Howard, 1986, p. 11.14).

A source of sound which rotates around a stationary subject will also elicit a nystagmus reflex and perceptions of self-rotation (Lackner, 1977b). This is termed audio nystagmus.

Various types of somatic stimulations will also elicit perceptions of self-motion accompanied with the nystagmus reflex and so are termed arthrokinetic nystagmus. For example nystagmus and (illusory) perceptions of self-motion have been shown to occur when a hand is placed on a circular wall which rotates around a (blindfolded and stationary) subject (resulting in shoulder articulation) (Brandt and Buchelle, 1977), or when blindfolded subjects walk in place (ie. stationary) on a circular conveyer belt (resulting in spinal, hip, knee, and ankle articulations) (Bles, 1981).

Nystagmus is a visual reflex which contributes to the perception of the orientation of the body relative to a stable exterior environment while the body is moving. It also assists rapid scanning. When the eyes scan across an environment then slow/fast nystagmus phases will reflexively occur. If the eye movement was continuous (no nystagmus) then the visual image would be blurred. Smooth eye movements (continual smooth eye motion with no nystagmus) will only occur during voluntary "tracking", that is, maintaining a fixation on a smoothly moving stimulus. When the background is visually distinctive then nystagmus will still tend to occur. Tracking the moving stimulus against a black background will allow most success in completely inhibiting the nystagmus reflex (Hallett, 1986).

APX. II.36b Vision of the body moving.

Sensory data from the vision of one's own body is also a dominate source of information contributing to kinesthesia. We know our body positions and movements because we can see them. This source of data is overlooked in most discussions of kinesthesia, perhaps because it would be considered visual-spatial information. Since the vision of the body provides data about body moves and poses it can properly be considered to be kinesthetic.

Indeed, information from the vision of the body appears to be given more perceptual reliability. For example, somatic sensory data can be intentionally ignored but data from the vision of the body cannot be ignored and thus will dominate the spatial memory (Klein and Posner, 1974; Reeve et al., 1986). Greater amounts of vision of the body results in more accurate recall of body poses, regardless of greater or lesser amounts of somatic sensory data (Adams et al., 1977). Visual spatial data typically tends to dominate the perception of kinesthetic spatial data (see APX. IV.12). The perception and learning of limb positions and movements is also possible even when all somatic nerves have been severed (in monkeys) and vision of the body together with efferent data (see below) are the only sources of kinesthetic information (Taub and Berman, 1968).

APX. II.37 Audio Receptors.

The structure of the outer ear truly begins with the body itself. As sound approaches the ears it may bounce off, or be "shadowed" by the shoulder and the head. The neck and entire body allow the position of the ears to be rapidly and precisely shifted. The bilateral positioning allows two separate samples of the incoming auditory stimuli.

The outer ear proper begins with the outermost, visible, cartilaginous part termed the auricle (or pinna). Its expanded shape serves to collect sound waves and channel them into the narrow auditory canal which guides the waves to the tympanic membrane (ear drum).

The middle ear consists of three tiny bones forming a linkage which transfers and amplifies the vibration from the tympanic membrane to the inner ear. The bony linkage may also be vibrated directly through the bones of the skull (eg. the sound of clicking you own teeth together).

The vibrations are transferred to the thick lymphic fluid within the spiral-shaped cochlea of the inner ear. The vibrations create waves in the lymphic fluid which move up the cochlea and stimulate tiny hairs on its interior surface which are connected to nerve endings. Stimulation of hairs at the base of the cochlea's spiral produces a perception of high pitch and stimulation towards the tip of the spiral produces a perception of low pitch. (General references for audio receptors; Kapit and Elson, 1977; Scharf and Buus, 1986; Scharf and Houtsma, 1986.)

Similar to the processes of visual kinesthesia, two types of audio information can be distinguished. These can be termed audio field motion and audition of the body moving.

APX. II.37a Audio field motion.

Analogous to visual field motion, when an organism travels or rotates through space the surrounding sounds of the stable environment will be in motion relative to the organism's ears. This audio field motion contributes to the subject's perception of self-motion and a stable environment. Audio field motion is an important kinesthetic cue and can create illusions of self-motion and accompanying nystagmus by rotating a sound around a blindfolded, stationary subject (Lackner, 1977b).

APX. II.37b Audition of the body.

Our use of sensory data from the audition of the body is included in Gibson's (1966, p. 37) concept of "auditory proprioception" and its importance can be practically experienced by attempting a kinesthetic task with plugged ears. Body movements can be heard internally through the bones and externally through the outer ear. We also hear the effects of our movements (eg. the sound of each key tapping on a typewriter). This auditory feedback provides data regarding the bodily movements.

APX. II.38 Efferent Data.

A mechanism is hypothesized whereby we have an internal knowledge of the motor commands which have been initiated. This is sometimes termed "efference" (*e*fferent commands as opposed to *a*fferent feedback). It might be considered that efferent data is fundamentally different than the peripheral sensory feedback of other types of kinesthetic data. However, efference can be considered to be a central or internal feedback loop which serves as a "motor memory storage system operating without the requirement of peripheral feedback" (Kelso, 1977b, p. 34). This central feedback is thought to be available to establish a stronger memory representation together with other peripheral kinesthetic feedback (Larish et al., 1979). Efferent data provides useful information about the body's movements and positions and so is a vital contributor to kinesthesia.

One source of evidence for the existence of efferent data is that monkeys who have had their somatic nerves surgically severed can still learn and perform gross limb movement and positioning tasks (eg. walking, climbing up a wire cage, reaching and grasping for food) (Taub and Berman, 1968; Taub et al., 1973; Bossom, 1974) or be trained to point at visual targets without sight of the limb (Bossom and Ommaya, 1968; Taub et al., 1975) (though accuracy for fine movements such as grasping small objects did not develop normally). After more time these monkeys were able to execute normal gross movement while also blindfolded or with the reaching hand out of view. In addition, monkeys with surgical somatic deafferentiation of forelimbs and blinding on the day of birth still learned to use the limbs for gross tasks such as supporting weight, walking, linking forearms (though more learning time was required overall and reaching toward objects could not develop) (Taub et al., 1973). Since sources of somatic information have been eliminated it is hypothesized that efferent information, and also sometimes vision of the body, is used to perceive the body movements and positions.

Efference is also indicated by research which demonstrates that subject's actively produced movements to end-positions of their own choice can be recalled better than if the experimenter manipulates the subject's passive arm. Presumably efferent data is produced when the movements and positions are generated actively by the subject and this data is available to derive an accurate perception (see active versus passive limb positioning; APX. II.43).

Other evidence comes from the reaction time required to correct an error in an executed movement. The time required to perceive, process, and react has been measured at 190-260 msec for visual feedback (Keele and Posner, 1968) or 108-169 msec for somatic feedback (Higgins and Angel, 1970). However, movement errors can be corrected as fast as 83 msec from the moment of initiation (Higgins and Angel, 1970). This rapid ability to correct one's own movement errors is therefore attributed to a knowledge of efferent data rather than sensory feedback.

Two theories about the nature of the interior knowledge of motor commands are termed "efference copy" and "corollary discharge". Corollary discharge (Teuber, 1974) posits that a copy of motor commands is sent to perceptual centers where it influences the interpretation of the raw sensory data. Efference copy (Jones, 1972; 1973; Von Holst, 1954) posits that a copy of the motor commands are saved for future executions of the same movement and to compare to other kinesthetic data (eg. from joints and muscles). Clark and Horch (1986, p. 13.57) illustrate the two theories with diagrams. Kelso (1977b) compares efferent copy with corollary discharge in a linear positioning task and found that simply forming the motor plan in one's mind did not result in as accurate kinesthetic memory as when also actively executing the motor plan. This indicates that the most useful "efferent discharge" (p. 34) or "efferent information" (p. 42) is generated by actually executing the motor plan, rather than simply reading an efferent copy of the commands without having executed them.

For the purposes of this study this difference is not critical. The knowledge of motor commands can be generally referred to as efferent data of efferent information.

APX. II.40 Deriving Kinesthetic Perceptions

Kinesthetic perceptions are rarely derived from a single sensory organ located in one part of the body. Instead, sensory data from many types of receptors is integrated into a single kinesthetic perception. The variety of receptors contributing to kinesthesia provides sensory redundancy so that if one group of receptors fails to function another group can still provide the necessary information.

This section reviews how particular stimulations are derived into particular types of perceptions. Types of kinesthetic perceptions distinguished here include the sense of balance or equilibrium; the sense of linear, rotary, or circular self-motion; limb position sense; limb movement sense; and the sense of force or exertion.

APX. II.41 Sense of Balance, Equilibrium.

The sense of balance is closely related to the perception of the gravitational vertical which is most readily sensed by the vestibular otolith organs. Also, the physical weight of the body and its gravitational alignment through the joints (translated from the upper-most to the lower-most body-parts) is sensed by pressure-sensitive joint receptors throughout the body (Clark, 1975) and the entire weight of the body is sensed by pressure-sensitive skin receptors against the ground.

The alignment of the body-weight relative to gravity may also be sensed by tension-sensitive tendon receptors. That is, the closer the body alignment to the gravitational vertical, the more equal the tension between opposing tendons. Though, prolonged periods of adaptation to an off-vertical position may create a somatic misperception of vertical since the receptors have become so "used to" the off-vertical alignment. When this subject's body is placed into gravitational alignment the subject will (mistakenly) perceive that they are out of line with gravity because their somatic receptors have become so adapted to the off-vertical alignment.

Visual field motion (or non-motion) may be the most important for the sense of balance as anyone can testify who tries to stand on one leg with their eyes closed. Posture is most stable when the eyes are focused on a fixed point (Hellebrandt and Franseen, 1943). Visual field motion which occurs when a subject sways or falls off of balance will induce reflex motor reactions to counter the sway and maintain balance. When this type of visual field motion is artificially induced with a "swinging room"* infants will fall over (Lee and Aronson, 1974) and adults will experience body sway (Lishman and Lee, 1973), especially in unusual stances (Lee and Lishman, 1975). Similar postural sway will occur when projections of moving visual scenes are presented to subjects' peripheral visual field (Lestienne et al., 1977).

* The "swinging room" moves around the subject while the floor remains stable. Thus the subject experiences visual field motion but no accompanying stimulations from somatic or vestibular receptors (pictured by Lishman and Lee, 1973, p. 289).

Maintenance of equilibrium through visual field stimulations is most effective with a textured visual stimulus whereby even slight lateral visual field motion can be readily detected (viz. a texture of vertical lines is more effective than horizontal lines), and this texture is most effective when presented to the peripheral visual field (Amblard and Carblanc, 1980).

APX. II.42 Sense of Self-Motion.

The term "self-motion" is used here to refer to motion which either 1) translates the entire body in a straight line through space to a new location (linear self-motion), 2) turns the entire body around an axis (rotary self-motion), or 3) a combination of translation and rotation (circular self-motion). In contrast, "limb-motion" refers to the motion of body-parts relative to other body-parts (see IIA.32).

Limb-motion often occurs together with self-motion (eg. motion of the limbs while walking) but the two can also be separated (eg. self-motion forward while riding in a train with the limbs held still). When self-motion occurs by riding on a train, boat, elevator, etc. without any active participation by limb-motion it is referred to as "passive movement" (Rock, 1968) or "passive locomotion" (Johansson, 1977). Three types of self-motion will be considered here; linear self-motion, rotary self-motion, and circular self-motion (For reviews see: G. J. Andersen, 1986).

APX. II.42a Sense of linear self-motion.

During linear self-motion the subject travels through space along a straight line to a new location. This is also referred to as "translation" (Andersen, 1986, p. 56; Warren et al., 1988) or "locomotion" (Johansson, 1977; Strelow and Babyn, 1981).

Somatic and vestibular receptors would seem to provide the basis for perception of linear self-motion since it is the muscles, tendons and joints which produce the movement and the vestibular receptors sense the acceleration and deceleration. Despite this, somatic and vestibular sensations are dominated by reliance on visual field motion. This is so robust that illusions of self-motion can be easily induced. Common examples are when the train on the next track begins to move and it is initially perceived as one's own train moving (or if a large truck begins to move next to one's car), or when standing close to a large river a perception of self-motion (rather than motion of the river) may occur.

Self-motion illusions, referred to as "linear vection" or "induced translation" (G. J. Andersen, 1986; Bles, 1981), have also been produced in the experimental setting. Lishman and Lee (1973) used a "swinging room" to induce illusions of self-motion and found that "the effects are practically universal" (p. 292). Subjects' knowledge that they were actually standing on a stable floor and that the "room" was swinging around them did not change the strength of the illusion of self-motion.

When visual field motion is presented only to the periphery of the visual field the illusion of linear self-motion occurs even when accompanied by conflicting vestibular and somatic sensations (Berthoz et al., 1975; Johansson, 1977). This agrees with studies of the effect of visual field motion on the sense of balance when the greatest effect came from peripheral rather than central vision (Amblard and Carblanc, 1980; Lestienne et al., 1977). This same effect has been found in studies of rotary self-motion (see below). Illusions of linear self-motion can also be induced from a radially expanding pattern with an apparent internal depth (eg. from motion parallax and occlusion visual cues) which is presented only to the central visual field (Andersen, 1986, p. 58; Andersen and Braunstein, 1985).

Conversely, if visual field motion is absent (in a dark room) then subjects (incorrectly) perceive that an exterior object is moving rather than (correctly) perceiving their own passive self-motion. Even if somatic and vestibular stimulations are available from repeated accelerations and decelerations (Rock, 1968) or from voluntary jogging (while attempting to stay in place) (Glanzmann, 1987) subjects will usually not perceive their own self-motion if visual field motion is absent.

The direction of linear self-motion can be more accurately performed when visual field motion is available (ie. with a visible background texture rather than darkness or isolated objects in the foreground) (Strelow and Babyn, 1981). Judgements of the heading are more accurate when a high density of visual field texture is available (Warren et al., 1988).

APX. II.42b Sense of rotary self-motion.

The perception of rotary self-motion is closely associated with the vestibular semi-circular canals since these respond to rotational accelerations and decelerations. Nevertheless, even in the absence of vestibular stimulations illusions of rotary self-motion with accompanying nystagmus can be induced from isolated somatic stimulations (Brandt and Buchelle, 1977; Brandt et al., 1977; Lackner and Dizio, 1984), somatic stimulations together with efferent information (Lackner and Dizio, 1984), audio field motion (Dodge, 1923; Lackner, 1977b), or visual field motion (see below). Illusions of rotary self-motion induced by visual field motion are referred to as "induced rotation" or "circular vection" (around the vertical axis), "roll vection" (around the sagittal axis) or "pitch vection" (around the lateral axis) (G. J. Andersen, 1986).

Circular vection is typically induced by rotating a circular wall with a textured surface around a stationary observer. Reducing the luminance levels so that the visual field motion is only perceptible by peripheral vision (Leibowitz et al., 1979), masking the central visual field, or presenting stimuli rotating in the opposite direction in the central visual field, has no effect on the illusion of self-motion, whereas masking peripheral vision eliminates the illusion (Brandt et al., 1973). This type of evidence indicates that peripheral visual field motion is primarily responsible for the perception of rotary self-motion. The importance of peripheral over central vision has also been found in inducing roll vection (Brandt et al., 1975; Held et al., 1975; Reason et al., 1982).

Although illusions of rotary self-motion can be induced by visual field motion alone, when both visual field motion and vestibular stimulations are available the perception of self-motion is quickest and speed estimates are the most accurate (Melchner and Henn, 1981). This indicates how visual and vestibular data function together in the perception of self-motion. Illusions induced from visual field motion are tied to characteristics of the vestibular receptors. With very slow accelerations of the visual field, the self-motion illusion is immediately perceived (Melcher and Henn, 1981). This immediate perception presumably occurs because during slow rotary accelerations very little vestibular stimulations would be expected. However, when the visual field accelerates quickly the self-motion illusion is perceived only gradually, not reaching its full effect until after 30 seconds (Brandt et al., 1973; Wong and Frost, 1978). This latency in the onset of the self-motion illusion presumably occurs because during quick accelerations the vestibular canals would be stimulated during actual rotary accelerations. The illusion of rotary self-motion occurs after the same time that it would take the lymph fluid to stabilise in the vestibular canals during an actual rotation.

The importance of vestibular stimulations in perceptions of rotary self-motion also reveal themselves when illusions of rotary self-motion are induced around a sagittal axis (roll vection). To induce roll vection a subject observes a rotating visual field on a plane parallel to the frontal plane of their body (Held et al., 1975, p. 258). In this case, rather than perceiving a continuous bodily rotation (as in circular vection) the observer perceives that their body is tilted up to a maximum of about 15° (Dichgans et al., 1972; Held et al., 1975). The greater the visual field texture, the greater the illusion of tilt (Brandt et al., 1975; Reason et al., 1982).

Presumably an illusion of a complete 180° roll vection does not occur because during an actual rotation around the sagittal axis (eg. a cartwheel) vestibular otolith stimulations would occur indicating the body's reorientation relative to gravity. When the same rotating visual-field in the frontal plane is presented to subjects who are lying on their backs, then full 180° roll vection illusion is perceived. In this case the sagittal body axis is oriented along the gravitational vertical and so vestibular otolith stimulations would not be expected during an actual self-motion. Furthermore, when subjects are lying on their backs and the rotating visual field is presented at an angle directly in front of their tilted head, then subjects (incorrectly) perceive that their head is horizontal and their body is tilted. This incorrect perception of head orientation allows the full 180° rotary roll vection illusion to be experienced, presumably because when the head is perceived to be horizontal then there would not be any vestibular otolith sensations expected during an actual rotation (Dizio and Lackner, 1986).

APX. II.42c Circular self-motion.

Locomotion in a curved path can be referred to as circular self-motion and consists of a combination of rotary and linear self-motion. These translation and rotation components must both be distinguished by the perceiver for accurate performance of circular self-motion (Rieger, 1983).

As with rotary and linear self-motion, visual field motion is most important for the perception of circular self-motion. When visual field data is not available (eg. a dark room) then circular self-motion will not be perceived even with available vestibular stimulation. Visual field motion alone, or somatic stimulations with efferent knowledge (walking on a circular conveyor belt) are sufficient to elicit illusory perceptions of circular self-motion when the subject actually remains in the same place (ie. no vestibular stimulation). When somatic and efferent data would indicate that the subject was traveling forwards (walking forward on a circular conveyor belt) but contradictory vestibular stimulation would indicate that the subject was traveling backward (the high speed of the conveyor belt caused the subject to actually be traveling backwards) then the vestibular data is ignored and the illusory circular self-motion is perceived in accordance with the somatic and efferent data (Bles, 1981).

APX. II.43 Limb Position Sense.

Sensory data from the vision of the body dominates the perception of limb position. Recalling an arm position is more accurate when the arm can be seen than if it can not (Adams et al., 1977; Posner, 1967). Seeing one's own limbs is the most accurate way of knowing where they are.

A great deal of research has been devoted to discerning the non-visual mechanisms of position sense (for reviews see McCloskey, 1978; Clark and Horch, 1986). Early work recorded discharges from sensory endings in cats' joint receptors and found that each sensory ending had a maximum response which ranged over a few degrees of joint positions and that these ranges were different for different sensory endings. This was interpreted as indicating that perception of limb position arises solely from joint receptors (Adams et al., 1977, p. 13; Andrew and Dodt, 1953; Gibson, 1966; Roland, 1979; Skoglund, 1956). Even though this notion has been overwhelmingly shown to be erroneous (see below) it is sometimes still adhered to in current texts on dance and exercise (Ellison, 1993, p. 75; Fitt, 1988, p. 266).

In subsequent research joint receptor responses were found to be inadequate for the perception of limb position. Using a different technique for recording joint receptor discharges (for details see McCloskey, 1978, pp. 766-767), Burgess and Clark (1969) found that only 4 out of 278 slowly adapting afferent fibres from the posterior nerve of the cat knee joint were maximally activated at intermediate (rather than extreme) joint angles. In addition, 140 fibres were maximally activated at *both* full flexion and also full extension of the joint. Clark and Burgess (1975) continued this research and found that only 6 out of 672 fibres tested in the medial nerve, and 45 out of 713 fibres tested in the posterior nerve of the cat knee joint gave slowly adapting responses to intermediate joint angles. Similar results were found in other studies (Clark, 1975; Grigg, 1975). Because joint receptors respond primarily to extreme joint angles, rather than intermediary joint angles, the general conclusion of these findings was that "articular receptors in the knee are not capable of providing appreciable steady-state position information over most of the working range of the joint" (Clark and Burgess, 1975, p. 1462).

Receptors in different joints may have different response characteristics than those in the cat knee joint. For example, nerves for receptors in the cat hip joint have been found to discharge at intermediate joint positions (Carli et al., 1979). Nevertheless, other research findings have shown that anesthetized knee joint capsules in man (Clark et al., 1979) surgical replacement of finger or toe joints with silicone implants (Cross and McCloskey, 1973; Kelso et al., 1980), or deafferentiated joint and skin receptors from a pressure-cuff around the limb (Goodwin et al., 1972a; Roy and Williams, 1979) has no effect on position sense. Therefore, while joint receptors provide some data for position sense their role does not appear to be crucial.

Other research has indicated the role of muscle spindle receptors in the perception of limb position. When the joints, muscles, and skin of the hand are paralysed (by local injection of anaesthesia or by a pressure cuff which cuts off circulation causing total numbness) subjects can still perceive flexion/extension movements and the resultant positions of the fingers, presumably because this perception arises from the long muscles acting on the fingers but which are located in the (non-paralysed) forearm. This perception became even more accurate when the subject lightly tensed the muscles in the forearm (which would increase the data coming from muscular receptors) (Goodwin et al., 1972a; 1972b). The completeness of the anaesthesia within the hand was verified since subjects could not detect lateral finger movements nor could they distinguish between movements at different joints of the same finger. These are movements which are not effected by the long muscles of the forearm, rather, in order to detect or perform these movements, the muscles, skin, or joints within the hand would have to be active (Goodwin et al., 1972b, p. 327).

Further evidence for the role of muscular spindle receptors in the perception of limb positions comes from experiments in which a biceps or triceps tendon is stimulated with a physiotherapy vibrator (placed on the skin above the tendon) which causes a reflex contraction of that muscle (thought to originate from the stimulation of the muscle's spindle receptors). When the other arm is used to duplicate the perceived motion and position of the vibrated arm (which is hidden from vision), a position illusion (sometimes more than 40°) was evident. The subject perceived the arm position as if the vibrated muscle was stretched longer than it actually was (Goodwin et al., 1972a; 1972c).

If the tonic vibration reflex is allowed to shorten the vibrated muscle then the correct direction of motion will be perceived (viz. elbow flexion if biceps are vibrated, elbow extension if triceps are vibrated) but the distance of movement will be underestimated so that the vibrated muscle is perceived to be stretched longer than it actually is (Goodwin et al. 1972c). If the tonic vibration reflex is not allowed to articulate the elbow (the forearm is restrained by the experimenter or if the subject voluntarily contracts the antagonist muscle) so that an isometric contraction occurs (no change is muscle length), then the elbow will be perceived to be articulating just as if the vibrated muscle was lengthening (Goodwin et al., 1972a; 1972c; McCloskey, 1973).

These position and movement illusions are so robust that even subjects who are informed about the procedure will still perceive the illusions (Goodwin et al., 1972c, p. 1383). This vibration technique can even lead to perceptions of impossible wrist positions, or to perceptions of simultaneous multiple forearms (Craske, 1977).

Using the same vibration technique, McCloskey (1973) separated the illusion of movement from the illusion of position. Velocities of the motion illusion were too fast to have been equated with the size of the position illusion. Longer durations of the vibration caused no change in the position illusion whereas it produced a continual illusion of movement. Loading the muscle (placing a weight on the end of the limb) slowed the velocity of the movement illusion but increased the size of the position illusion. And, with lower frequencies and greater amplitude of vibration the movement illusion was eliminated but the position illusion persisted.

Since muscle spindle primary endings are the most sensitive to vibration it was concluded that these receptors are responsible for the illusions (Goodwin et al., 1972a, p. 744; 1972c, p. 1384). But during lower frequency and greater amplitude vibrations the secondary spindle endings may also play are role in the position and movement illusions (McCloskey, 1973, p. 130).

Further support for the role of muscular receptors in position sense comes from the common finding that arm positions which are actively moved to are recalled better than positions which are imposed by the experimenter onto the subject's passive arm (Jones, 1972; Kelso, 1977b; Marteniuk, 1973; Paillard and Brouchon, 1968; 1974). When muscles are actively contracting there will be greater sensory discharges from muscle spindle receptors (Matthews, 1933; McCloskey, 1978, p. 770), tendon receptors (Jansen and Rudjord, 1964) and joint receptors (Grigg, 1975; Skoglund, 1956) which should provide more sensory feedback.

This effect of better position recall from active movements also indicates the use of efferent data for deriving the perception of limb position. This is demonstrated when subjects are allowed to actively move their arm to an end-location of their own choosing. In this type of subject-generated movement efferent data would be available and recall of the end-location is most accurate.

Kelso (1977b) distinguishes between factors which may lead to superior memory for self-produced movements: 1) The movement may be actively executed by the subject (active) or the subject's arm may be passively moved by the experimenter (passive). 2) The end-position of the movement may be chosen by the subject (preselected) or it may be defined by the experimenter with a physical stop on the experimental positioning apparatus (constrained). The combination of active movements to preselected end-locations produces the greatest accuracy. When subjects actively execute preselected end-locations then these can be recalled accurately even with deafferentiated joint and skin receptors in the hand during finger movements (Roy and Williams, 1979). When the active movement is abruptly stopped at an unexpected (constrained) end-location, then this cannot be recalled any better than if the movement was passive (Jones, 1972). A limb position produced by active limb movement can be matched by the opposite limb better than if the position was produced by passive movement (Paillard and Brouchon, 1974). These results indicate that efferent data and muscle spindle receptors are both contributing to the perception and recall of limb positions.

Other studies have also indicated the use of efferent data in limb position sense (eg. Lashley, 1917). Even without any somatic stimulations (when nerves have been severed) after two to six months the vision of the body and efferent data can be sufficient for successful limb movement and positioning in monkeys (eg. climbing up a wire cage or reaching and grasping for food), though this condition does not yield as much accuracy as when somatic stimulations are also available. After more time these monkeys were even able to accomplish the movement task while blindfolded or with the reaching hand out of view (efferent data being the only remaining source of information) (Bossom, 1974; Taub and Berman, 1968).

However, in these deafferentiation studies fine movements such as grasping small objects do not develop to normal accuracy without somatic stimulations (Taub and Berman, 1968; Taub et al., 1973). This indicates that somatic stimulations are necessary for fine positioning and movement.

Skin receptors have also been shown to play a vital role in position sense for certain body areas with a high density of skin receptors. Anesthetized skin around the hands has a detrimental effect on its position accuracy (Moberg, 1983) though anesthetized skin around the knee has no effect (Clark et al., 1979).

Another approach is to suggest that it is not joint angle which is sensed but limb orientation relative to gravity. Soechting (1982) demonstrated that producing an identical forearm orientation was more accurate than producing an identical elbow joint angle. In this approach the pressure sensitivity of joint receptors (Clark, 1975; Clark and Burgess, 1975) could be contributing since the pressure torque in a joint would be in a constant relation with that limb's orientation to gravity.

Position sense degrades over time. The longer an arm is held in a static position, the less well its position can be matched by the opposite arm (Paillard and Brouchon, 1968; 1974). Presumably this occurs because sensations from quickly adapting receptors are no longer available after a brief time with no movement.

APX. II.44 Limb Movement Sense.

The perception of limb movement is tied to the perception of limb position since a position can only be reached by a movement, and every limb movement leads to a new position. This relation is exemplified in the studies of active versus passive produced movements in which the accuracy of body position recall was dependent on the quality of the movement (active vs. passive), with active movement leading to the most accurate position recall (see APX. II.43).

However, other evidence reveals that limb movement and limb position are separate. For example, if a very slow speed is used to articulate the knee joint the new position will be perceived but the movement will not (Horch et al., 1975). This leads to the conclusion that perceptions of movement arise from quickly adapting receptors while perceptions of position arise from slowly adapting receptors. The uncorrelated illusions of limb position and limb movement induced by placing a physiotherapy vibrator against the skin over a muscular tendon (see APX. 11.43) also indicate that position and movement are separate perceptions (McCloskey, 1973).

Just as with position sense, limb movements can be learned with information from the vision of the body together with efferent knowledge, and eventually with efferent knowledge alone (Bossom, 1974; Taub and Berman, 1968; see APX. II.43). Vision of the body can also dominate perceptions of limb movement. Subjects can learn a letter-writing task from vision of the body and efferent data with all somatic stimulations eliminated (from a pressure cuff causing total arm numbness) though fine control is best when both vision of the body and somatic stimulations are available (Laszlo and Baker, 1972). A sequence of horizontal linear arm movements was also learned better after one practice trial by simply watching the visual pattern of the movements than by watching the pattern and also bodily performing it (Klein and Posner, 1974). (For discussion of memory and recall characteristics of visual, somatic and audio space, see APX. IV.)

APX. II.45 Sense of Force; Sense of Exertion.

Perceptions of an object's weight, or of the amount of force exerted against an object, can be derived from pressure-sensitive skin and joint receptors and tension-sensitive tendon receptors. In certain situations audition of the body would also contribute information about the amount of force which the body has exerted (eg. the sound of the body impacting upon an object). A typical procedure used when estimating an object's weight is to actively move the object upwards and downwards. This may assist perception since the force required to set the object into motion and then to stop its motion, provides amplified pressure and tension sensations.

The weight of an object is perceived to be heavier when the muscles lifting it are fatigued (McCloskey et al., 1974). Therefore the perception of force appears to be related to the efferent data about the amount of exertion expended. When a reflexive contraction of the muscle is induced (by a physiotherapy vibrator) then subjects can distinguish between the force encountered by the muscle, and the exertion ordered by the motor commands (Ibid). This indicates that the sense of force may be derived by somatic receptors while the sense of exertion is derived from efferent data.

APX. II.50 Summary: Kinesthesia

Kinesthesia is identified as arising from sensory stimulations via receptors in muscles, tendons, joints, skin, vestibular apparatus, eyes, ears, and also from an interior knowledge of motor commands (efferent data). This assortment of stimulations from throughout the body are derived into perceptions of balance and equilibrium, self-motion, limb-motion, limb position, and force or exertion.

APPENDIX III

SPATIAL COGNITION VERSUS VERBAL COGNITION

A great deal of research has demonstrated that spatial cognitive processes and verbal cognitive processes use separate cognitive resources. For example, Haber (1970) reviews the different storage capacities and different memory codes for verbal versus pictorial memory. This forms the basis of "multiple-resource theory" or "specialized resource pools" (Pritchard and Hendrickson, 1985), also known as "multi-channel" models of cognitive information processing (as opposed to "single-channel" models). According to single-channel models, cognitive attention can be allocated to only one task at a time, whereas according to multi-channel models cognitive attention can be allocated to separate tasks simultaneously (eg. Allport et al., 1972; McLeod, 1977) (for details about the types of spatial tasks, see Appendix V). This has been developed into the model of "working memory" which includes the rehearsal/processing mechanisms referred to as the "visuo-spatial scratch pad" for spatial processing and the "articulatory loop" for verbal processing (eg. Baddeley, 1986).

APX. III.10 Dual-Task Interference

Much of the research probing the existence of multi-channels of information processing comes from "dual-task interference" studies (also called time-sharing decrement; divided attention; dual task effects; or interpolated tasks effects) in which a Subject undertakes two separate tasks simultaneously (or a 2nd interpolated task is undertaken while information from the 1st task is being held in memory for later recall). Performance on each task undertaken individually is compared with performance on the tasks undertaken simultaneously. Results reveal that sometimes the two tasks interfere with each other and so a performance decrement will occur when the two tasks are undertaken simultaneously. However, sometimes the two tasks can be performed simultaneously just as well as they can be performed individually. Since no performance decrement occurs in these cases it is interpreted as indicating separate cognitive resources are devoted to each of the two tasks.

Brooks (1967) used a 4 x 4 matrix as a visual-spatial pattern in which the spatial contents of a sentence could be visualised (later known as "Brooks' matrix"). It was found that visually reading a sentence which describes a pathway through the matrix results in a decrement to recalling the pathway whereas hearing the sentence (vision not involved) did not decrease performance on the spatial matrix task.

Brooks (1970) extended these findings with a cross-shaped matrix which could be used to visualise the spatial content of a sentence (eg. "the goat is to the left of the rock and above the fountain"). Subjects were asked to mentally rotate (eg. clockwise) the spatial arrangement depicted by the sentence and to state the new spatial relations (in this case: "the goat is to the right of the fountain and above the rock"). Responses to the mental rotation task were fastest if the Subject simply heard the sentence, or heard the sentence and also saw the matrix, but responses were slower when the Subject was required to visually read the sentence.

Both of Brooks' (1967; 1970) experiments indicate that the use of vision when reading interferes with the use of the visual system for visualising the spatial matrix. Thus, visual reading and spatial visualisation appear to utilise the same cognitive resources.

Brooks (1968) found comparable results with different tasks. Two types of response were used, either 1) pointing with the arm to the correct answer within a spatial layout, or 2) speaking the correct answer. In a verbal classification task (categorising each word in a sentence as a noun or a verb) the pointing response was faster than speaking. Conversely, in a spatial classification task (categorising the type of corner within a visualised line diagram) speaking the answer was faster than pointing at the answer. These results indicate that the same cognitive resources which are used for (spatial) pointing and for visualisation are different than the cognitive resources which are used for verbally speaking and verbal classification.

These findings were extended. A (kinesthetic spatial) pursuit rotor tracking task performed simultaneous with Brooks' tasks resulted in a performance decrement to Brooks' spatial tasks, but not to Brooks' verbal tasks (Baddeley et al., 1975). The pursuit rotor tracking task also resulted in a decrement to word recall from each of two types of visualisation mnemonic strategy but had no effect on a verbal mnemonic strategy (organising words into alphabetical order) (Baddeley and Liberman, 1980).

Phillips and Christie (1977b) refined Brooks' findings by showing that simple interpolated tasks (visually reading numbers, seeing an unattended spatial matrix, or seeing an unattended spatial arrangement of dots) did not cause a decrement to a spatial matrix recognition task. However, when the interpolated task required more cognitive resources (eg. mentally adding the numbers, actively remembering the interpolated spatial matrix), then a decrement did occur on the spatial matrix recognition task. These results indicate that spatial visualisation is not interfered with by the visual sensory modality *per se*, but only when a cognitive representation of the visual sensation is actively formed.

Logie (1986) found that a spatial matrix recognition task, an unattended spatial matrix, or unattended line drawings, presented during retention each resulted in a performance decrement to word recall for Subjects using a visualisation mnemonic strategy, but resulted in no decrement to word recall for Subjects using a rote rehearsal strategy. Conversely, unattended audio-verbal stimuli during retention resulted in a decrement to the rote rehearsal verbal memory strategy but not to the visualised verbal memory strategy. Thus, the spatial tasks interfere with other spatial tasks (visualisation) but do not interfere with verbal tasks (rote rehearsal).

Allport and Colleagues (1972) used verbal "shadowing" (listening to a verbal monologue and simultaneously reciting the same words) during the learning of other tasks. The verbal shadowing resulted in a large decrement to recognising other spoken works, a smaller decrement to recognising printed words, a very small decrement to recognising visual pictures, and no decrement to simultaneous piano sight-reading. In addition, the simultaneous piano sight-reading resulted in no decrement to answering questions about the content of the verbally shadowed material. Thus, the verbal and spatial tasks appear to be relatively independent.

Verbally classifying sounds was found to result in no decrement (one tone to be identified; Wickens, 1976) or only a small decrement (two different tones to be identified; McLeod, 1977) to a simultaneous (kinesthetic spatial) tracking task. However, classifying the sounds by a kinesthetic spatial response of pressing one of two buttons did cause a decrement to spatial tracking (McLeod, 1977). Similarly, remembering groups of three consonants (eg. "XTR", "MPT") did not cause a decrement to a (kinesthetic spatial) linear positioning task (Schmidt and Ascoli, 1970).

Remembering the spatial locations of numbers or letters within a 5 x 5 spatial array resulted in a decrement to recognising schematic faces or photos of model airplanes, whereas remembering the verbal identity of the numbers or letters in the array resulted in less or no decrement (Salthause, 1974). Recognising graphic characters resulted in a greater decrement to recalling the spatial locations of numbers or letters within the array but a lesser decrement to recalling their verbal identities. Conversely, counting backwards by threes resulted in a greater decrement to recalling the verbal identities of the letters or numbers within the array, but a lesser decrement to recalling their spatial locations (Salthouse, 1975). In all cases the two spatial tasks interfere with each other and the two verbal tasks interfere, but there is less interference between the spatial and the verbal task.

A longer time is required to recognise a visual spatial histoform pattern after a task of comparing visual spatial graphic symbols than after comparing words (Pritchard and Hendrickson, 1985). Continuous tapping on a 5 x 5 spatial array resulted in a decrement to recalling visual locations (the locus of a circle within an empty square) but verbal articulatory counting did not result in a decrement (Morris, 1987). Continuously verbally reciting "1, 2, 3, 4" resulted in a decrement to a verbal judgment task (eg. is a statement true or false) but had no effect on a concurrent spatial judgment task (which hand of a manikin is holding a square, sometimes requiring a mental rotation of an image of the manikin). Conversely, continuous spatial 4-key tapping resulted in a decrement to the spatial judgment task (when mental rotation was required), but not to the verbal judgment task (Farmer et al., 1986).

In all cases discussed above the two spatial tasks interfere with each other's performance, and the two verbal tasks interfere. However a spatial task does not interfere, or interferes very little, with a concurrent verbal task. This indicates that verbal tasks and spatial tasks use separate, parallel, cognitive resources.

APX. III.20 Neuropsychological Evidence

Other evidence for multi-channel models comes from studies of patients with neurological disease or injury. Often the ability to solve one type of cognitive task has been damaged while ability for other types of tasks remains normal. This is also interpreted as indicating the use of separate cognitive resources devoted to the different tasks. Much of this work has also contributed to the general notion of specialisation of the right cerebral hemisphere for spatial tasks and the left cerebral hemisphere for verbal tasks.

The study of cerebral lateralization is not fully reviewed here (see Fried et al., 1982; Kosslyn, 1987). In general, spatial tasks are performed better if the stimuli is presented to the left visual field (right cerebral hemisphere) and verbal tasks are performed better when presented to the right visual field (left cerebral hemisphere) (Paivio and Linde, 1982; Paivio and Ernest, 1971). However there are considerable differences between Subjects (Ojemann, 1979; Gur and Reivich, 1980) and in many cases the hemispheric superiority for verbal vs. spatial tasks is minimal (ie. both hemispheres perform either type of task equally well) or is reversed. This has been found to be associated with the hand used for writing and its writing posture (Levy and Reid, 1976). Right-handed normal writers and left-handed inverted writers exhibited the normal right-hemisphere spatial, left-hemisphere verbal superiority. In contrast right-handed inverted writers and left-handed normal writers had reversed hemispheric superiority.

Other evidence (De Renzi and Nichelli 1975; Hanley et al., 1991) typically finds that right-brain damaged patients perform just as well as normal Subjects in verbal memory tasks, whereas left-brain damaged patients are inferior. Conversely, right-brain damaged patients perform poorly on spatial tasks (Corsi blocks, Brooks' Matrix) compared to left-brain damaged patients and normal Subjects. Similar results were found by De Renzi and Colleagues (1977) who also identified the role of the posterior-brain (within both hemispheres) as critical for performance of spatial tasks.

The right/left, spatial/verbal dichotomy is not this simple. Luria (1970) describes how basic processes such as regulation of attention, selectivity of stimuli, discrimination of stimuli, recoding, organising information, storing information, and the analysis and synthesis of information into coherent wholes are located in both hemispheres throughout the brain and underlie the more complex spatial and verbal processes. In Trevarthen's (1978) experiments the right cerebral hemisphere (left visual field) showed superiority for "recognition of faces, nameless shapes, familiar pictures, . . . and memorising appearance" while the left cerebral hemisphere (right visual field) was superior in "analysis of meaning or of combination of interchangeable features" and patterns of colour (p. 116). Trevarthen suggests that left-brain verbal and right-brain spatial specialisation is a result in these differences in hemispheric processing style.

Bradshaw and Nettleton (1981) assert that "The traditional verbal/nonverbal dichotomy is inadequate for completely describing cerebral lateralization", instead they describe "a continuum of function between the hemispheres, rather than a rigid dichotomy" (p. 51). They describe the left-hemisphere as utilising sequential, analytic, and focal mechanisms whereas the right-hemisphere utilizes diffuse, holistic, and parallel mechanisms.

APX. III.30 Dual-Coding: Multi-Coding

The separate modes of spatial versus verbal cognitive processing is also indicated by the effect of improved memory performance when both of these codes are attached to the same stimuli (eg. a verbal name and a visual image of the object to be remembered). In addition, a kinesthetic motor code can be identified which also improves memory performance.

APX. III.31 Spatial and Verbal Codes.

The "dual-coding hypothesis" proposes that the imagery system and the verbal system comprise two distinct symbolic systems which are involved in cognition (Paivio, 1978; 1979, p. 233). These two systems are analogous to the distinction between spatial and verbal information processing channels. When an item is remembered in terms of both its spatial image and its verbal label then it is said to be dual coded. When an item is dual coded it can be remembered better.

Several characteristic findings are indicative of superior memory performance from dual-coding. Concrete, image-evoking words (eg. names of physical objects) are more easily remembered than abstract words. This appears to indicate that when a visual image is easily created that the work is likely to be remembered (Elliott, 1973; Paivio, 1969). Rote repetition rehearsal leads to inferior verbal memory performance compared to visual imagery rehearsal (Bower, 1970b; Bower and Winzenz, 1970; Elliott, 1973). Images were found to be generated faster for concrete than abstract words (Paivio, 1975). Correspondingly, sentences with a high potential for imagery can be verified faster (eg. is the sentence true or false) than sentences in which forming an image is difficult (Jorgensen and Kintsch, 1973). Changes in wording is more noticeable in abstract sentences than in concrete sentences. Presumably this occurs because abstract sentences are stored in memory in their verbal form since they are not easily visualised. However, concrete sentences appear to be stored as spatial images and so changes in the wording (as long as the overall meaning does not change) are not readily noticed (Begg and Paivio, 1969). Memory for nonsense abstract line drawings is better when a verbal interpretation is also provided (Bower et al., 1975).

Similar types of dual-coding have a long history of use in various types of strategies for improving memory from the ancient Greeks through to modern times. Many of these mnemonic strategies utilise a large group of imagined spatial locations (eg. rooms in a building). An image of each item-to-be-remembered is visualised as being at each of the locations. During recall the Subject simply imagines a walk through the building and recalls the image present at each of the locations. A variety of these memory strategies have been reviewed by Bower (1970a), Yates (1966), and Paivio (1979, pp. 153-175).

Dual-coding can also assist in recalling body movements. In an (kinesthetic spatial) angular positioning task the use of verbal labels (the time on an imaginary clock face) led to more accurate recall than having no labels after a filled retention interval (counting backwards by 3s) (Ho and Shea, 1978) or after an unfilled retention interval (Shea, 1977). Winter and Thomas (1981) found similar results with a variety of age groups.

APX. III.32 Levels of Processing.

Ho and Shea (1978) point out that the effects of improved recall as a result of dual-coding (words and pictures; or words and movements) can be encompassed within the "levels of processing" model of memory. In Craik and Lockhart's (1972) initial presentation they proposed a model of memory that was based on a continuum from surface memory to deep memory (as opposed to short-term and long-term memory). Recall performance is considered to be a function of the "depth" to which the particular item-to-be-remembered has been processed.

By "depth" Craik and Lockhart (1972) mean that an item receives "a greater degree of semantic or cognitive analysis" (p. 675). They distinguish between "type I processing" which consists of rote repetitions of the sensory aspects of the items (eg. the particular sounds of words or shapes of pictures), and "type II processing" which consists of semantic elaborations of the items (eg. meaningful and expressive interpretations). The depth of processing, and memory performance, is thought to increase as a result of type II processing.

Attempts have been made to identify more specific measures of "depth". Craik and Lockhart (1972, pp. 675-676) describe "elaboration" as creating depth. Similarly, Anderson and Reder (1979) and Bradshaw and Anderson (1982) equate "meaningfulness" of an item with the spontaneous tendency for learners to make "elaborations" relative to that item. They reason that more elaborations occur with more meaningful items because these readily evoke associations within the learner's existing memory structure. Every elaboration is one connection to the learner's existing memories, thereby integrating a new item into memory by relating it to existing items in memory. The more ties to existing memories a new item receives, the more likely it can be recalled at a later time. For example, the more associations made to a story (Bower, 1976; Hayes, 1979), or the greater the meaningfulness of visual forms (Bower et al., 1975; Goldstein and Chance, 1970), the better these items are remembered.

The problem with "meaningfulness" is that it can sometimes be detrimental to memory, not by forgetting, but by "remembering" too much. That is, if a large number of elaborations have been made relative to a highly meaningful item then more is remembered about that item than was actually there to begin with. For example, extra events may be added when recalling a story (Hayes, 1979), or visual forms may be recognised when in fact they have never before been seen (Price, 1968).

"Distinctiveness" can be seen as the complementary process to "elaboration". Rather than associating an item with other items in memory, "distinctiveness" improves memory performance by contrasting the item from the rest of memory, thus making the item more distinguishable from other similar memories (Jacoby and Craik, 1979). For example, when learning nouns by forming mental images the greater the uniqueness or bizarreness of the images, the better the recall of the nouns (Lesgold and Goldman, 1973). It is also observed that unusual objects in a visual scene receive the longest duration of attention and are remembered better than usual objects in the scene (Berlyne and Ditkofsky, 1976; Friedman, 1979).

While elaboration creates associations among many related memories, distinctiveness isolates the memories and so makes it easier to tell them apart. Thus, both of these factors appear to be important for "depth". Craik (1983) asserts that memory must be meaningfully related to other knowledge, but also distinguished from that knowledge, that is, "more elaborate, and more precise" (p. 355). Eysenck (1979) also finds that elaborations (ie. "inter-item relationships") are vital for the recall of memories, while distinctiveness (ie. uniqueness) is vital for recognising or separating memories from each other. Concepts of "relational" and "item-specific" information (Hunt and Einstein, 1981; Hunt and Seta, 1984) are comparable to elaboration and distinctiveness respectively. They find that memory is superior when both types of information are encoded, that is, both similarities and differences.

Dual-coding can be understood within the levels of processing framework.

When Subjects generate multiple codes these create greater elaboration and distinctiveness for the items-to-be-remembered.

APX. III.33 Verbal Dominance in Dual-coding.

In some cases when verbal labels are attached to stimuli, the memory for those stimuli does not necessarily improve. Rather, the verbal labels appear to be relied upon and the details of the stimuli may be forgotten.

When a visual shape was verbally labeled Subjects later remembered the shape as conforming to the label and being less like the original shape (Carmichael et al., 1932; Daniel, 1972). In some cases drawing abstract shapes from memory (Ranken, 1963) or recognising pictures of buildings (Pezdek and Evans, 1979) is more accurate when verbal labels are not used during learning.

Visual shapes with a high association value (ie. they readily evoke verbal associations) were recognised less well than shapes with a low association value (Price, 1968). This poor recognition performance was the result of "false alarms", that is, the high association value led Subjects to believe they had seen some shapes before when in fact they had not. This effect of false recognitions induced by verbal labels has also been found for recognising faces (Klatzky et al., 1982) or abstract shapes after a retention interval (Nagae, 1980).

Verbalising the content of scenic photographs increased the ability to recognise different views of the same scene but had no effect on the ability to recognise the identical photo (Bartlett et al., 1980). The number of verbal associations which a Subject makes regarding photos of faces, inkblots, or snowflakes, had no correlation with the likelihood of that photo being later recognised. These researchers conclude that "verbal mediation" is not important in spatial recognition memory (Goldstein and Chance, 1970).

Reliance on verbal labels is frequently demonstrated. Hirtle and Jonides (1985) created a map in which buildings of the same verbal category (eg. government buildings, recreation buildings) were arranged in small groupings. When one building was farther away from its appropriate group then its location would be (incorrectly) recalled as being closer to its group. That is, the actual spatial location was displaced towards members of the same verbal category. In another experiment (Hirtle and Mascolo, 1986) points on a map tended to be clustered together in recall according to their verbal labels rather than their actual locations. McNamara and

Lesueur (1989) randomly arranged pairs of related verbal labels into various locations within a spatial array. While distance estimations between locations was equally accurate regardless of whether the labels were related or not, the distance estimations could be made faster between nearby verbal labels when they were related.

Schooler and Engster-Schooler (1990) propose the hypothesis of "recoding interference" in which spatial memories are biased by recoding the stimuli verbally. They found that verbally describing a face led to decreased accuracy in later recognising that face, while simply visualising the face (without verbalising) had no effect on recognition performance. This same recoding interference occurred in a task of colour recognition. They also review similar evidence by D. F. Hall (1977) in which Subjects who discussed the characters of a face with a forensic sketch artist performed less well on later recognising the actual face.

However, some research has demonstrated an improved recognition performance for verbally labeled abstract shapes (Ellis, 1968) or schematic faces (McKelvie, 1976) when the verbal labels direct the Subject's attention to details which will be important in the recognition test. When the label does not encourage attention to critical details then it does not benefit recognition performance.

APX. III.34 Motor Enactment / Motor Imagery Multi-code.

Another type of memory code is proposed which consists of a motor image. This motor code has been identified as separate from both visual spatial and verbal codes.

Short sentences describing body actions (eg. "eat the apple"; "knock on the table") have been used for stimuli and have been referred to as "action phrases" (Engelkamp, 1988a; Engelkamp and Zimmer, 1984), "action events" (Cohen et al., 1987) or "mini-tasks" (Nilsson and Cohen, 1988). An action phrase might be motor encoded in three different ways, motor enactment, observed enactment, or imagined enactment. A variety of terminology has been used for describing these three types of enactment.

Motor enactment encoding occurs when the verbal action phrase is physically performed by the Subject. This has been variously referred to as "motoric enactment", "M-processing" (Saltz, 1988), "motor encoding" (Engelkamp, 1986), "physical enactment" (Nilsson and Cohen, 1988), "Subject performed tasks" (Cohen, 1981; Cohen et al., 1987; Nilsson and Cohen, 1988), "performing actions" (Engelkamp, 1988b), or simply "doing" (Engelkamp, 1988a; Engelkamp and Zimmer, 1984).

Observed enactment encoding occurs when the verbal action phrase is physically enacted by another person and this is observed by the Subject. This has been variously referred to as "experimenter-performed-tasks" (Cohen and Heath, 1988; Cohen et al., 1987), "observed tasks" (Cohen, 1981) or simply "seeing" (Engelkamp, 1988a).

Imagined enactment encoding occurs when the Subjects hears the verbal action phrase and then visualises this action occurring. This has been variously referred to as "forming images of the actions" (Engelkamp, 1988a), "visual encoding" (Engelkamp, 1986) or as a "cognitive enactment" (Nilsson and Cohen, 1988).

Another possibility is the standard verbal encoding when the verbal action phrase is presented to the Subject who is simply instructed to remember it. This has been variously referred to as the "standard learning instruction" which consists of "listening only" (Engelkamp, 1986; 1988a), "verbal repetition" (Engelkamp and Zimmer, 1984), as encoding only the "task instructions" (Cohen, 1981; Cohen et al., 1987) or simply as the "verbal task" (Nilsson and Cohen, 1988).

Enactment encoding has a powerful effect on verbal learning. It appears that enactment encoding creates such a good memory that additional processing has no further beneficial effects. The typical dual-coding effect is that nouns are recalled better than verbs, presumably because nouns readily elicit a dual-code of word plus visual image (see above). However, when verbs are encoded with an enactment strategy then nouns and verbs are recalled equally well (Engelkamp, 1986; 1988b; Engelkamp and Zimmer, 1990). Enactment encoding was also found to facilitate memory for lists of nouns and for sentences without "obviously enactable verbs" (ie. "to wish"). Thus, enactment encoding is not limited to verbs but is also applicable to the potential actions associated with nouns and also more abstract concepts (Saltz, 1988).

Many strategies that typically improve verbal recall have no effect on recall from enactment encoding. Allowing Subjects to generate their own words-to-be-remembered (rather than the Experimenter presenting the words) typically results in improved verbal recall (the "generation effect"). However, Subjects' self-generated verbal action phrases and motor enactments did not lead to better verbal recall of the action phrases than when the action phrases were presented by the Experimenter (Nilsson and Cohen, 1988). When the meaningful aspect of words is given attention during learning it typically results in better recall than when the sensory or phonic aspects of the word is given attention (ie. levels of processing), but this had no effect on memory from an enactment learning strategy (Cohen, 1981). Certain verbal phrases were identified by the experimenter as being especially important to remember, or rated by Subjects as being most likely to be remembered. When these verbal phrases were learned by simply hearing the phrase then the important or most likely to be remembered phrases were recalled best. However, when the verbal phrases were learned through motor enactment or observed enactment they were all recalled equally well (Cohen, 1983). Typical verbal recency and primacy effects* also do not occur for memory from enactment encoding (Cohen, 1981; Nilsson and Cohen, 1988).

In all these cases it appears that the enactment learning strategy leads to such good verbal recall performance that other factors have no further beneficial effects. Thus, enactment learning is believed to provide an "optimal encoding" (Nilsson and Cohen, 1988, p. 427) or an "inherent richness" (Cohen et al., 1987, p. 110) whereby the items are automatically learned at a "deep" level (Cohen, 1983).

In some research motor enactment and observed enactment lead to equally good levels of recall performance (Cohen, 1983; Cohen et al., 1987) while in other research motor enactment leads to better recall than the equal performance from observed enactment or imagined enactment (Engelkamp, 1988b). Motor enactment has been found to lead to better recall of a verbal action phrase than observed enactment or simply planning for a motor enactment. It is assumed that a motor enactment consists of the activation of a motor program. This is fully activated during a motor enactment, but only partially activated during planning or observing an enactment (Engelkamp,1988a, pp. 298-299).

Likewise, Engelkamp and Zimmer (1984) found that questions about the body movements described in a verbal action phrase could be answered faster if the phrase

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* When recalling a series of words the most recently presented items are typically recalled best (recency effect) and the initially presented items are recalled second best (primacy effect). The recency effect is attributed to those items still being present in short-term memory, and the primacy effect is attributed to these earliest presented items having had the longest time for rehearsal, and therefore being well established, in long-term memory (Atkinson and Shiffrin, 1971; Glazner, 1972; Peterson, 1966).

had been learned with motor enactment, but questions about the physical objects described in the verbal action phrase could be answered faster if the phrase had been learned with verbal repetition. They conclude that motor enactment accesses the motor program and so prepares the Subject for questions about the movements, but this does not assist semantic judgements. Thus, motor actions are seen as a separate memory sub-system.

Saltz and Donnenwerth-Nolan (1981) used a dual-task interference study to distinguish between motor imagery, visual imagery, and verbal rehearsal. They found that motor enactment and imagined enactment both led to better recall of sentences than verbal repetition. A secondary task of visualising a picture resulted in a decrement to sentence recall from the imagined enactment strategy but not to the motor enactment strategy. Conversely, a secondary task of physically performing the actions of several verbs resulted in a decrement to sentence recall from the motor enactment strategy but not to the imagined enactment strategy or to the verbal strategy. Finally, a secondary verbal task resulted in a decrement to sentence recall from the verbal repetition strategy but not to the enactment strategies. These dual-task interference effects indicate that verbal repetition, visually imagined enactment, and motor enactment all appear to be utilising separate cognitive resources.

Recall of the verbal action phrases appears to be based on recalling the motor actions rather than recalling the object acted upon. By mixing verbal action phrases to create a phrase with a highly recalled movement action together with a poorly recalled object acted upon, and vice versa (a poorly recalled movement action and a well recalled object), it was found that the movement action predicted the probability that an action phrase could be verbally recalled. This occurred with motor and observed enactment and also with standard verbal learning (Cohen et al., 1987).

Studies of motor enactment typically involve the recall of verbal phrases, presumably assisted by a multi-code which includes both the words and motor information. Visual spatial recall can also be assisted with a multi-code which includes motor information. A multi-code of visual seeing and kinesthetic tracing abstract letter-like shapes led to better visual shape recognition than learning the shapes by vision alone (Hulme, 1979). Arm movements into the correct locations on a large Brooks' matrix task did not improve matrix recall over learning the matrix with no overt body movements, however movements into the wrong matrix locations (disrupting any possible multi-code) resulted in a decrement to matrix recall (Quinn and Ralston, 1986).

APX. III.40 Conclusions.

A great deal of research has demonstrated that spatial cognitive processes and verbal cognitive processes use separate cognitive resources. This forms the basis of multi-channel models of information processing. Much of the research comes from "dual-task interference" studies in which a Subject undertakes two separate tasks simultaneously. The typical result is that two concurrent verbal tasks will interfere with each other, and two concurrent spatial tasks will interfere with each other, however a spatial task and a verbal task can often be performed as well simultaneously as either task can be performed individually. This is interpreted as indicating separate spatial versus verbal cognitive resources.

Other evidence for multi-channel models comes from studies of Patients with neurological disease or injury when the ability to solve one type of cognitive task has been damaged while ability for other types of tasks remains normal. This is also interpreted as indicating the use of separate cognitive resources devoted to the different types of tasks. Much of this work has also contributed to the general notion of specialisation of the right cerebral hemisphere for spatial tasks and the left cerebral hemisphere for verbal tasks (which is shown to not be a fixed relationship).

Separate modes of spatial versus verbal cognitive processing are also posited by the "dual-coding hypothesis". When both a verbal and a spatial code are learned for the same item then it is said to be dual-coded and can usually be remembered better. Similar types of dual-coding have a long history of use as mnemonic strategies from the ancient Greeks to modern times. Dual-coding can also facilitate the recall of body movements. A kinesthetic-motor code ("enactment") can also be identified which also facilitates verbal memory when it is dual-coded together with a verbal phrase. Motor enactment learning strategy leads to such good verbal recall performance that other factors have no further beneficial effects and so is thought to provide an "optimal encoding" or an "inherent richness". This superior memory performance from dual-coding can be explained according to the "levels of processing" model of memory.

However, in some cases when verbal labels are attached to stimuli the memory for those stimuli does not necessarily improve. Rather, information in the verbal labels appears to be relied upon and the actual details of the stimuli may be forgotten.

APPENDIX IV

SPATIAL INFORMATION PROCESSING

Within spatial cognitive processes, separate modes of spatial information can be distinguished (for details about the types of spatial tasks, see Appendix V).

APX. IV.10 Separable Visual, Audio, and Kinesthetic Spatial Modalities

Spatial information can be perceived through visual, audio, and kinesthetic perceptual-motor systems. In many cases these perceptual systems exhibit separate perceptual, retention, and retrieval characteristics.

Hulme (1979) experimented with childrens' visual recognition of abstract letter-like shapes, either learned through vision alone or learned through a combination of vision and kinesthetic tracing of the shape. A secondary kinesthetic shape recognition task during retention resulted in a greater decrement to the combined kinesthetic + visual learning condition than to the visual learning condition. However, a visual shape recognition task during retention caused a decrement to both learning conditions equally. This indicates a dual-task interference which is specific to the particular perceptual-motor system. Kinesthetic space interfered with kinesthetic space, visual space interfered with visual space, but kinesthetic space only slightly interfered with visual space.

The three modes also work together. For example, audio spatial perception is most accurate when head movements (even small covert movements) are allowed and when the eyes are free to see (even though there may be no recognizable relationship between the audio spatial pattern and the pattern of eye movements) (Ruff, 1985; Warren, 1970). Thus, both kinesthesia and vision play a part within audio spatial perception.

Saltz and Donnenwerth-Nolan (1981) used a "visualisation" versus an "enactment" strategy for remembering words within sentences. Visual inspection of pictures resulted in a decrement to the visual image mnemonic (visualising the actions within a sentence) but had no effect to the motor enactment mnemonic (physically enacting the actions within a sentence). Conversely, physically enacting the meaning of verbs resulted in a decrement to the motor enactment mnemonic but not to the visualisation mnemonic. Thus, visual and kinesthetic processes appear to use separate cognitive resources.

APX. IV.11 Intra- and cross-modal spatial positioning.

It is well documented that performance on spatial positioning tasks is better when learning and recall are both visual, or both kinesthetic ("intra-modal"), but performance is worse when learning is visual and recall is kinesthetic, or vice versa ("cross-modal") (Connolly and Jones, 1970; Jones and Connolly, 1970; Diewert and Stelmach, 1977; Newell et al., 1979; Reeve et al., 1986). Apparently spatial accuracy decays when information is translated from one perceptual-motor system to another.

In spatial positioning tasks the visual-to-visual intra-modal condition is initially equally accurate (Connolly and Jones, 1970; Posner, 1967) or is initially more accurate (Diewert and Stelmach, 1977) than the kinesthetic-to-kinesthetic intra-modal condition. Accuracy in the visual-to-visual condition is not effected by an unfilled retention interval but suffers a performance decrement from a visual task during that interval. Conversely, the kinesthetic-to-kinesthetic condition becomes less accurate after an unfilled retention interval (Newell et al., 1979) but suffers no further decrement from a visual task (Jones and Connolly, 1970) or from a digit classification task (Posner, 1967) during the retention interval. These results led researchers to the conclusion that visual spatial information receives central cognitive processing and so is rehearsable during a retention interval, but that this rehearsal may be disrupted by an interfering task. Conversely, kinesthetic spatial information was not considered to be rehearsable during retention and so looses accuracy at a set rate regardless of other tasks during retention.

Marteniuk (1973) disputed this conclusion by demonstrating that kinesthetic spatial information could retain its accuracy by intentional "imagining" rehearsal during retention. This indicates that kinesthetic spatial information does receive central cognitive processing.

The relative accuracy of the cross-modal conditions seems to vary. Connolly and Jones (1970; Jones and Connolly, 1970) found that the kinesthetic-to-visual cross-modal condition was initially more accurate than the visual-to-kinesthetic condition. When retention intervals were tested the kinesthetic-to-visual condition and the visual-to-visual condition were effected similarly. Also, the visual-to-kinesthetic and the kinesthetic-to-kinesthetic conditions were effected similarly. Therefore Connolly and Jones concluded that, regardless of mode of learning, if recall is to be visual then memory storage would be visual (and rehearsable) whereas if recall is to be kinesthetic then memory storage would be kinesthetic (and not rehearsable).

This conclusion was found to be questionable since visual recall is not always the most accurate. The visual-to-kinesthetic condition is sometimes more accurate than the kinesthetic-to-visual condition (Diewert and Stelmach, 1977) or these two cross-modal conditions may be equally accurate (Newell et al., 1979). In addition, the supposed mode of memory storage was manipulated by telling the Subject that the response was to be kinesthetic, and then requiring a visual response (or vice versa). This had no effect on accuracy and so the memory storage of the spatial information appears to be independent of the planned mode of recall (Newell et al., 1979).

APX. IV.12 Visual Dominance of Spatial Information.

It is well documented that visual spatial information tends to dominate spatial information from kinesthesia and audition (Posner et al., 1976).

In a letter-drawing task Laszlo and Baker (1972) found that kinesthetic practice (no vision allowed) led to worse visually guided recall (when somatic stimulations were eliminated by a pressure-cuff causing arm numbness) than having no practice at all. When all perceptual feedback was eliminated (efferent data the only remaining source of information) then letter-drawing performance was superior for visually practiced Subjects than kinesthetically practiced Subjects. These results were interpreted as indicating that kinesthetic spatial information develops a dependence on itself and so is not readily translated into other modes of spatial information, whereas visual spatial information is readily translated into other modes.

In a line-drawing task Klein and Posner (1974) found that visual learning alone led to more accurate performance than combined kinesthetic and visual learning. When recall was to be visual and Subjects are instructed to attend to the visual but ignore the kinesthetic stimulations then performance improved to be equal with visual learning alone. Conversely, kinesthetic learning (no vision) resulted in a more accurate kinesthetic recall than combined visual and kinesthetic learning, even if Subjects were instructed to ignore the visual stimulations (this finding was reproduced by Reeve et al., 1986). These results indicate that if visual information is available that it cannot be ignored and will dominate the spatial memory. Whereas kinesthetic spatial information can be ignored and thus have no effect.

Adams and Colleagues' (1977) results agree with this. Greater amounts of visual information led to more accurate performance on a spatial positioning task regardless of higher or lower amounts of kinesthetic information. Reducing the amount of visual information between learning and recall decreased performance accuracy regardless of kinesthetic information being reduced or remaining unchanged. Thus, visual spatial information appears to determine the task skill regardless of the degree of kinesthetic information.

Analogous effects can be identified in the dominance of kinesthetic perceptions arising from "visual kinesthesia" regardless of stimulations from somatic receptors (Lishman and Lee, 1973; see IIA).

Visual dominance has also been identified when discrepant information is presented to the different perceptual systems ("sensory conflict"). Sensory conflict can be created by displaced vision (looking through prisms which displaces the visual field) and by displaced audition (a "pseudophone" which laterally displaces the direction of the heard sound). The perceived visual direction towards the location of a finger, or towards the source of a sound, dominated the spatial information from somatic and auditory stimulations. The perceived kinesthetic direction in which an arm is reaching to touch the source of a sound also dominated the audio perception of the source of the sound (Pick et al., 1969). Thus, it appears that visual information is given the greatest perceptual authority, then kinesthesia (somatic stimulations), and auditory spatial information is given the least authority. Correspondingly, Willott (1973) found that kinesthesia dominated auditory spatial perception. The kinesthetic perception of the alignment of a rotating bar (moving the bar with the arms/hands) dominated the audio perception of the bar's alignment (sounds coming from speakers which the Subject believes are at each end of the bar).

Rock and Harris (1967) also found the dominance of visual spatial over kinesthetic spatial information. In several spatial tasks such as judging the size and shape of small quadrangles, pointing at a visual, audio, or kinesthetic direction, or drawing doodles, letters and numbers, they found that when vision was displaced or reversed (by Subjects looking through prisms) that the apparent visual direction was believed and kinesthetic stimulations were discounted. Eventually the kinesthetic system adapted so that stimulations were interpreted to correspond to the new (illusory) visual spatial perception. This adaptation was so robust that Subjects would write numbers and letters backwards (which appeared normal when viewed through the reversing prisms) without being aware of the reversal. This adaptation of kinesthesia to correspond to the dominant visual spatial information is a typical effect in studies of perceptual adaptation by looking through prisms (see Appendix VI).

APX. IV.20 Unitary Spatial Memory System

Although visual, audio, and kinesthetic perceptual-motor systems may sometimes exhibit different perceptual and memory characteristics, in other cases there is evidence that all sources of information are integrated into a single spatial representation.

What was initially conceived of as "visual memory" (eg. Baddeley et al., 1975; Phillips and Christie, 1977a) was later refined into a unified concept of "spatial memory" which is devoted to performing spatial tasks perceived through any modality. Baddeley and Lieberman (1980) demonstrated that audio spatial tracking (pointing at the unseen source of a moving sound) interfered with performance of Brooks' spatial matrix but not Brooks' verbal task. Likewise, skill in audio spatial tracking was poorer during concurrent execution of the spatial matrix task than during concurrent execution of the verbal task. This indicates that audio spatial tracking and the Brooks' spatial matrix task both draw on the same resources within a unitary spatial memory. Similarly, Bairstow and Laszlo (1978a) found that kinesthetic tracing of an abstract form (with no vision), or visual tracking of a light which traces the form, each resulted in equal performance for visually recognising a picture of the form.

Solso and Raynis (1979) created a set of abstract shapes by deriving several variations of a single prototype shape. Some variations were similar to the prototype while others were very different. Several of the shapes were learned by either visually seeing the shapes or by kinesthetic tracing of the shapes (no vision). When Subjects later saw a shape which was similar to the prototype it would be recognised whether or not it had actually been learned earlier. Since this effect occurred regardless of the learning method (visual or kinesthetic) it was concluded that "the internal representation of geometric figures experienced by one modality is similar to the internal representation of the same geometric figures experienced by means of another modality" (p. 710). They refer to this similarity of representation, regardless of the mode of stimulation, as "second order isomorphism".

In addition, Millar (1990) reviews how "images" do not need to be visual but that blind Subjects often report auditory images, kinesthetic images, and images of skin texture and temperature. Typical cognitive tasks which are considered to require visual-spatial processes (eg. mental rotation and inferring new pathways within a cognitive map of the environment) can also be successfully performed by Subjects who have been blind from birth. Kerr (1983) demonstrates that characteristics of spatial image processing (eg. the time to scan across a distance within an image; the time to identify features of various sizes within an image; mnemonic effectiveness) are identical for both sighted and congenitally blind Subjects. The only difference being that sighted Subjects are able to form a spatial image faster than blind Subjects. Neisser and Kerr (1973) have also shown that spatial images of an environment also include objects which would normally be concealed from vision and that this type of image is effective mnemonically. These research findings indicate that separate visual, audio, and kinesthetic spatial information is united into a single unitary special memory representation.

APX. IV.30 Location versus Configuration Information Types

A variety of evidence indicates that there are two fundamental distinct types of spatial information. These can be referred to as configuration and location spatial information types.

Smyth and Colleagues distinguished between different spatial information types as indicated by types of body movement. Continually tapping a series of body-part locations (head, shoulders, hips) resulted in a decrement to learning a series of bodily configurations but had no effect on recalling locations in Corsi blocks. Conversely, tapping the locations of 4 keys resulted in a decrement to recalling Corsi blocks' locations but not to learning bodily configurations (Smyth et al., 1988). Similar results were found with slightly different tasks. Altering the configuration of the left hand by squeezing a soft tube resulted in a decrement to learning hand configurations with the right hand but had no effect on recalling locations in Corsi blocks. Conversely, a 4-key tapping task (loci) resulted in a decrement to recalling locations in Corsi blocks, but not to learning hand configurations (Smyth and Pendleton, 1989). In further experiments watching a series of body figures resulted in a decrement to recalling a series of body figures, but watching a Corsi block task had no effect on recalling body figures. Conversely, watching a Corsi block task resulted in a decrement to performing a Corsi block task, but watching a series of body figures had no effect on Corsi block performance (Smyth and Pendleton, 1990).

From these results Smyth and Pendleton (1990) distinguish between movements "in which the location of a target in space is the goal" versus movements "in which the pattern or configuration of the body parts themselves is the goal" (p. 292). This second type of spatial movement is variously referred to as "movement patterns", "configured movements", "configural movement targets", or as "body shape" (pp. 291-292, 304). They identify a fundamental distinction between these two types of movement. A spatial location can be specified without regard to the body-parts which will be used to reach the location (body-part free) whereas spatial configurations are specific to certain body-parts (body-part specific) (p. 292). Smyth and Colleagues (1988) point out that spatial cognition research has primarily used spatial location information and that body figures have not been studied.

Distinctions analogous to this location/configuration distinction have been identified by other authors. Phillips (1983) proposes three distinctions within "classes of representation in visuo-spatial cognition": 1) object identity versus object location; 2) object classification versus object structural analysis; and 3) egocentric location versus exocentric location. The first distinction between object identity versus object location is analogous to the distinction between configuration versus location respectively.

Baddeley and Lieberman (1980, p. 537) propose a similar distinction between "visual" processes of pictorial and feature discrimination of *what* an object is (configuration), versus "spatial" processes of *where* an object occurs (location). In a dual-task interference study these two types of spatial information were experimentally distinguished. A spatial tracking task resulted in a large decrement to a visualisation word memory strategy which was strongly based on location information (experiment 4) but only half as much decrement to a visualisation word memory strategy which was based on an item's configuration or pictorial identity (experiment 3). The spatial location information required for the tracking task appears to have interfered with the location component but not with the configuration component of the visual images.

Byrne's (1974) concepts of "item concreteness" and "spatial organisation" are analogous to configurations and locations respectively. Drawings of common objects were arranged in separate locations within a spatial matrix. The drawings could be classified faster with a vocal response than by pointing with the arm to the correct answer. This was interpreted as indicating an interference between the location of a drawing within the matrix and the location requirements of the pointing response. However this interacted with the amount of overall configuration information available within the matrix. The advantage of the (verbal) spoken response over the (kinesthetic spatial) pointing response was small (1.6 sec.) when the drawings within the matrix could be perceived within a single overall picture or configuration (experiments 2, 4), but the advantage was large (3.7 sec.) when an overall configuration was not evident and so only location information was available. This comparison was not made by Byrne but it can be interpreted as indicating a lesser or greater degree of interference between the location information within the two concurrent tasks (remembering the location of a drawing, and pointing to that location with the arm). When an overall pictorial configuration was available then the requirements for remembering the locations of individual drawings was less (since the relative location of each drawing can be inferred from the overall picture, eg. the tractor is located on the ground, the clouds are in the sky).

Likewise, Breitmeyer and Ganz (1976, p. 27) consider visual "figural and location information" to be processed by "quasi-independent" cognitive resources. Zimmer and Engelkamp (1985) compare this distinction of figural versus location information to their distinction of a static visual subsystem for processing configurations versus a dynamic or kinematic visual subsystem for processing a series of locations.

The configuration/location distinction is also similar to the distinction between "shape" and "space" as they have been developed within the system of "Laban Movement Analysis" (For a review see; Maletic, 1987). Shape versus space are described as "the kind of bodily adaptation that may create the form" versus "the spatial lines and curves created by the end of a body part" (Dell, 1970, p. 63) or as the body's "process of shape change" in creating new configurations versus "revealing a clear spatial pull" towards an exterior location (Hackney, 1989).

Configuration and location also quite similar to the distinction between "body design" and "spatial progression" respectively as have been developed as part of "choreological studies". Whereas the body design refers to the sculptural configurations of the body itself, the spatial progression refers to the pathway through a series of exterior spatial locations (Preston-Dunlop, 1980, pp. 87-93; 1981, pp. 54-60; 1984, p. x).

APPENDIX V

VARIETIES OF "SPATIAL" STIMULI

A variety of stimuli have been used in experimental research which are considered to be "spatial". A review of these stimuli can give a group of the breadth of what is considered to be "spatial" knowledge.

APX. V.10 Spatial figures

Stimuli such as pictures, drawings, or solid objects can be considered to be examples of spatial figures. These can be perceived and or retrieved through the visual-motor system (seeing the figure), audio-motor system (hearing a sound source which traces the outline of the figure), or the kinesthetic-motor system (touching or drawing the figure without vision).

Many types of spatial figures have been used as stimuli, including colour photographs of buildings (Pezdek and Evans, 1979), visual scenes (Allport et al., 1972; Byrne, 1974), model airplanes (Salthouse, 1974), photos of scenes containing actor, action, and object (Saltz and Donnenwerth-Nolan, 1981), abstract line drawings or coloured wallpaper (Broadbent and Broadbent, 1981), shades of colour (Schooler and Engstler-Schooler, 1990), abstract shapes varied from a prototype (Daniel, 1972; Ellis, 1968; Nagae, 1980; Ranken, 1963; Solso and Raynis, 1979), letter-like shapes (Hulme, 1979), ideographic characters (Prichard and Hendrickson, 1985), cookie-cutter shapes (Schwartz et al., 1975), randomly curved patterns (Bairstow and Laszlo, 1978a; 1980; Morasso, 1983a; 1986), squares of different sizes (Rock and Harris, 1967), schematic faces (Mckelvie, 1976; Salthouse, 1974), photos or video-taped faces (D. F. Hall, 1977; Klatzky et al., 1982; Schooler and Engstler-Schooler, 1990), line drawings of common animals (Logie, 1986), and 5 x 5 histoforms (Prichard and Hendrickson, 1985). In some cases a spatial figure is presented in one orientation and then must be recognised in another orientation, requiring a "mental rotation" of the spatial memory representation (Salthouse, 1975) (see below).

In many cases the figure is perceived and/or retrieved by physically drawing or tracing it. Examples include drawing letters and words with various body parts, various sizes, and in various orientations (Bernstein, 1984, pp. 109, 114; Merton, 1972; Raibert, 1977; Smyth and Wing, 1984, p. 12; Wing, 1978; 1980); visually seeing abstract objects with verbal labels, then later drawing the objects (Carmichael et al., 1932); visually presented letters which are then traced on paper with a pen mounted on the index finger (Laszlo and Baker, 1972); seeing randomly curved patterns, or tracing the patterns from a stencil, while producing it concurrently with the other arm or recalling the pattern later by drawing it or visual recognition (Bairstow and Laszlo, 1978a, b; 1980); learning a 4-point path with visual-motor perception, arm-hand moves, or walking, and recall it with the same or different body movements, in normal or retrograde order, with or without "shortcuts" (Levine et al., 1982); seeing and tracing around letter-like shapes (Hulme, 1979), cookie-cutter shapes (Schartz et al., 1975), or abstract geometric shapes based on a single prototypical shape (Solso and Raynis, 1979) and later recognising these shapes visually; comparing unseen figures by touch (Carpenter and Eisenberg, 1978; Marmor and Zaback, 1976); observing one's own hand through right-left reversing prisms while doodling-drawing then writing letters and numbers while blindfolded (Rock and Harris, 1967); seeing and touching a square and then drawing it at its perceived size (Rock and Harris, 1967); and hearing an unseen sound while it traces the outline of a simple figure, then tracing that figure with the hand (Ruff, 1985).

APX. V.20 Spatial array.

An assortment of spatial arrays have been used as spatial stimuli in which a group of items (eg. pictures, letters) are distributed throughout an area. Spatial arrays might be perceived and retrieved through the visual-motor system (seeing the array) or the kinesthetic-motor system (eg. placing objects in the array or pointing at their appropriate places).

Types of spatial arrays used as stimuli include a group of drawings of common items arranged evenly on a sheet (Byrne, 1974), the letters of the alphabet, or the numbers 1-25 randomly arranged in a 5 x 5 square or diamond shaped array (Salthouse, 1974; 1975). Some arrays are analogous to maps in which verbal labels (Hirtle and Mascolo, 1986; McNamara and LeSueur, 1989) or photos of buildings (Pezdek and Evans, 1979) are distributed throughout an area.

APX. V.30 Spatial matrix

A spatial matrix is similar to an array except that in a matrix the space is marked out in some sort of grid. Thus all the locations are clearly evident, even if they are empty. One type of matrix consists of a grid with a random arrangement of empty (white) and filled (black) squares. Various sizes of filled/unfilled matrices have been used (eg. 3 x 3 matrix with 9 squares; 4 x 4 with 16 squares; 5 x 5 with 25 squares) (Logie, 1986; Phillips, 1983; Phillips and Christie, 1977a; 1977b).

Brooks (1967) designed a matrix task in which a Subject is requested to read and/or listen to a short verbal "spatial message" or a "nonsense message" and then repeat it verbatim. Subjects were instructed how a 4 x 4 matrix (with one of the squares designated as the "starting square") could be visualised and used as an aid in remembering the verbal messages. An example of a verbal message containing spatial material is as follows:

> In the starting square put a 1.
> In the next square to the right put a 2.
> In the next square to the up put a 3.
> In the next square to the right put a 4.
> In the next square to the down put a 5.
> In the next square to the down put a 6.
> In the next square to the left put a 7.
> In the next square to the down put a 8.
> (Brooks, 1967, p. 291)

The resultant imaged matrix would appear as shown in figure APX.V-1. A verbal message containing nonsense material would also be used as a comparative verbal task. In this case the words quick, slow, bad, and good would be substituted for the spatial words right, left, up, and down respectively. This has become known as "Brooks' matrix" and has been used by other researchers (Baddeley, 1983; Baddeley et al., 1975; Baddeley and Lieberman, 1980; Idzikowski et al., 1983) including a matrix large enough to contain arm/hand movement (0.35 m^2) (Quinn and Ralston, 1986).

		3	4
	1	2	5
		7	6
		8	

Figure APX.V-1. Example of Brooks' Matrix (Brooks, 1967, p. 291).

APX. IV.40 Corsi blocks.

De Renzi and Nichelli (1975; De Renzi et al., 1977) describe what has become known as "Corsi blocks". Nine blocks (25 cm^3 each) are arranged in a random pattern on a large board. The experimenter "taps out" a series of the blocks and the Subject is asked to tap the blocks in the same order. The number of blocks in the series increases until the Subject cannot accurately tap them in the correct order. Corsi blocks has also been used by other researchers (Smyth et al., 1988; Smyth and Pendleton, 1989; 1990).

Corsi blocks has similarities to Brooks' matrix in that they both measure the "span" of memory, that is, how many locations can be recalled in a sequence. In Brooks' matrix the series of locations are visualised in the matrix while in Corsi blocks the series of locations are tapped on the blocks.

APX. V.50 Sequential Tapping

In a sequential tapping spatial task Subjects are required to continually tap an apparatus in a spatial arrangement, usually as fast as possible. Examples include using a hand-held stylus to tap four metal plates in a square arrangement (ie. 2 x 2 array) (Farmer et al., 1986; Smyth et al., 1988; Smyth and Pendleton, 1989), tapping a 5 x 5 array of keys in a certain order (Morris, 1987), or tapping a sequence of body-parts in a certain order (eg. top of head, shoulders, hips) (Smyth et al., 1988). When sequential tapping occurs entirely within a single location then the spatial component is minimal (Quinn and Ralston, 1986).

APX. V.60 Spatial Positioning

Spatial positioning consists of perceiving and remembering the location of a visual point or the distal end of a limb.

APX. V.61 Limb Positioning.

Two types of limb positioning tasks are referred to a linear and angular positioning. These are typically perceived and retrieved through the kinesthetic perceptual-motor system (moving a limb to a final location), however, the visual-motor system is sometimes also used by seeing the motion of a light (Diewert and Stelmach, 1977; Newell et al., 1979), seeing the handle of the positioning apparatus (Reeve et al., 1986) or seeing a line the appropriate length (Connolly and Jones, 1970; Jones and Connolly, 1970).

In linear positioning an apparatus consisting of a sliding handle along a linear track is used to produce a linear movement path of the hand. The Subject grasps the handle and moves it a certain distance or to a final location (Adams et al., 1977; Connolly and Jones, 1970; Diewert and Stelmach, 1977; Jones and Connolly, 1970; Reeve et al., 1986; Roy, 1977; Schmidt and Ascoli, 1970).

In angular positioning an apparatus consisting of a lever with a handle at the moving end and a pivot at the fixed end, is used to produce a curved movement path of the hand. The Subject grasps the handle of the lever and moves it a certain distance or to a particular location (Keele and Ells, 1972; Klein and Posner, 1974; Laabs, 1973; 1974; Marteniuk, 1973; Marteniuk and Roy, 1972; Posner, 1967; Roy and Williams, 1979; Stelmach and Wilson, 1970; Williams et al., 1969).

The movement distance or end locations in linear and angular positioning can be learned and retrieved under a variety of conditions. Sometimes the limbs used and/or the direction of movement is changed between learning and recall (Larish et al., 1979; Stelmach and Larish, 1980; Wallace, 1977). Other variables include passive or active movement, isolation of either distance or location recall, mental rehearsal or other interpolated tasks between learning and retrieval, and types or amounts of feedback available.

APX. V.62 Spatial Location Recall.

In a different type of spatial location recall, Subjects see the location of a stimulus, which they must later recall. Examples include seeing a small circle within a larger square, then recalling the location of the circle within an empty square (Arnheim, 1974, pp. 14-15; Morris, 1987); or recalling the location of a dot within a circle (Huttenlocher et al., 1991; Nelson and Chaiklin, 1980).

APX. V.70 Body-part Positioning

In some spatial tasks one body-part is attempted to be moved to the location, or in alignment with another body part (typically without vision) or into alignment with the gravitational vertical. The typical example is touching one's nose with the eyes closed. This can be referred to as body-part positioning. Varieties of this spatial task include aligning the ends of the index fingers of the right and left hands or aligning the end of a stylus in one hand with the index finger of the other hand (Paillard and Brouchon, 1968): making a mark under a table at the location of the hand on top of the table, aligning both hands on the top of a table at a certain distance apart (Rock and Harris, 1967); adjust a bar (kinesthetically or by giving verbal instructions) so that it is oriented parallel to the frontal plane of the body (Willott, 1973); adjusting a bar into alignment with the gravitational vertical by giving verbal instructions (Asch and Witkin, 1948a, b; Souder, 1972; Wapner et al., 1951a, b; Werner et al., 1951; Witkin and Asch 1948a, b) or by kinesthetically manipulating the rod (Wapner and Werner, 1952); indicating the median plane of the body by marking on a piece of paper (Werner et al., 1953); manipulating an unseen rod into alignment with the median plane (McFarland et al., 1962); or positioning the hands in a parallel orientation (Gibson and Backlund, 1963). Body positioning takes place under various conditions including visual field tilt, body tilt, simultaneous audio stimulations, or self-motion accelerations.

APX. V.80 Spatial Localization

Spatial localization tasks consist of indicating a particular location (typically beyond arm's length) by pointing with a body-part in the appropriate direction. This consists of creating a spatial line (eg. the line of the arm from the shoulder to the finger-tip) which is aligned in the same orientation as an imaginary line running from the Subject to the location being indicated.

Visual-motor localization consists of pointing towards a location which can be simultaneously seen. Examples include pointing towards a visual object without sight of the arm (Pick et al., 1969; Rock and Harris, 1967) or pointing toward the correct answer in a visual layout of many possible answers (Brooks, 1968; Byrne, 1974).

Audio-motor localization consists of pointing towards the location of a sound which cannot be seen. Examples include aligning a rod to point towards an unseen sound (Thurlow and Kerr, 1970), placing two unseen sounds so that a perceived line between them is parallel to the frontal plane of the body (Willott, 1973), or pointing with an unseen body-part toward an unseen sound (Pick et al., 1969; Rock and Harris, 1967; Thurlow and Kerr, 1970; Warren, 1970).

Somamotor localization consists of aligning two body-segments so that they are parallel, thus pointing in the same spatial direction. Examples include one hand/finger pointing in the same direction as the other hand/finger (Pick et al., 1969), manipulating an unseen rod so that it is parallel with the head's sagittal axis (Thurlow and Kerr, 1970), pointing with an unseen hand parallel to the head's sagittal axis (ie. "straight ahead") (Rock and Harris, 1967), or physically manipulating an unseen bar so that it is aligned parallel with the body's frontal plane (Willott, 1973).

Ideomotor localization can refer to pointing towards a location which is not directly perceived but is known only through memory images. Examples include pointing (blindfolded) towards a remembered location in the horizontal plane (Wyke, 1965); imagining facing a particular location and moving a stylus across a 9cm diameter disk in the direction towards another imagined location (Hintzman et al., 1981); pointing a "sighting tube" in the direction towards unseen locations in a familiar large room (Hardwick et al., 1976); aligning a pointing apparatus towards unseen locations along a previously experienced floor pathway (Presson and Hazelrigg, 1984; Presson et al., 1987), or imagining standing in a well known town and drawing a line in the direction towards another imagined location in the town (Moar and Bower, 1983).

APX. V.90 Spatial Tracking

Tracking can be conceived to be a type of spatial localization when the stimulus is moving. Various types of spatial tracking tasks have been devised which all utilise kinesthetic-motor activity.

In visual-motor tracking Subjects attempt to keep a cursor (seen on a computer display screen) as close to a specified target as possible by manipulating a control lever (Klein and Posner, 1974; McLeod, 1977; Wickens, 1976). In visual-motor eye-movement tracking Subjects maintain a fixed visual focus on a moving target with eye movements and sometimes also head/neck movements (Baddeley, 1983; Idzikowski et al., 1983; Morris, 1987). Movements of a linear or angular positioning apparatus (see above) is sometimes used as a stimulus for visual tracking which is later recalled by actually moving the positioning apparatus (Connolly and Jones, 1970; Diewert and Stelmach, 1977; Jones and Connolly, 1970; Klein and Posner, 1974; Reeve et al., 1986). Or a visually tracked light traces the outline of a figure which is later visually recognised (Bairstow and Laszlo, 1978a).

In audio-motor tracking Subjects attempt to continually point at the location of an unseen moving sound. A flashlight has been used to point at the unseen sound, when the light is on the sound source then the sound changes thus providing feedback (Baddeley, 1983; Baddeley and Lieberman, 1980). Perceiving the shape of a simple figure which is traced by an unseen sound source (Ruff, 1985) could also be considered to be a type of audio-motor tracking.

In "pursuit rotor" tracking Subjects attempt to keep the end of a hand-held stylus in contact with a spot which is moving in a circular path (Baddeley, 1983; Baddeley and Lieberman, 1980; Baddeley et al., 1975).

APX. V.100 Skilled Body Movements

Occasionally the spatial aspects of skilled body movements are used as experimental stimuli. For example, piano sight-reading involves the spatial task of visually reading the music as printed on the page and the spatial task of touching the appropriate piano keys (Allport et al., 1972; Shaffer, 1981).

APX. V.110 Abstract Body Movements or Poses

Abstract body movements, or moving into abstract body poses, have also been used as spatial stimuli. Typically the bodily pose is specified and the movement to attain that pose is incidental, depending on the initial starting body position. Examples include moving from a neutral position (arms by the side and feet together) into one of several positions (eg. arms straight overhead, knees bent) (Smyth and Pendleton, 1990; Smyth et al., 1988); learning a series of hand configurations, and squeezing and releasing a soft tube (thus continually changing the hand configuration) (Smyth and Pendleton, 1989).

APX. V.120 Visual Imagery Mnemonic

Spatial imagery is used as a technique to improve memory for verbal stimuli. The use of a combined spatial-plus-verbal memory strategy has been developed into the "dual-coding hypothesis" which proposes that the spatial imagery system and the verbal system comprise two distinct symbolic systems which are involved in cognition (Paivio, 1978a; 1979, p. 233). When both a verbal and a spatial code is learned relative to the same item, then it is said to be dual-coded and can be remembered better.

A well-known example is the "'one-bun' rhyming mnemonic system" (Paivio, 1979, pp. 173-174, 247-248, 334-335) which has been used in experimental research (Baddeley and Lieberman, 1980; Logie, 1986). A Subject first learns a number-word rhyme: "one-bun, two-shoe, three-tree, four-door, five-hive, six-sticks, seven-heaven, eight-gate, nine-wine, ten-hen" (Paivio, 1979, p. 335). The first word-to-be-remembered is learned by visualising it in some sort of interaction with a bun, the second word is visualised in an interaction with a shoe, and so forth. At the time of recall the number (eg. one) serves as a cue which elicits memory for the rhyming "pegword" (bun), which in turn serves as a cue for the visual-spatial image of the bun in an interaction with the first word-to-be-remembered.

Other examples include imagining the actions of a sentence as a strategy for remembering the sentence (Cohen, 1981; 1983; Cohen et al., 1987; Engelkamp, 1986; 1988a; 1988b; Engelkamp and Zimmer, 1984; 1990; Nilsson and Cohen, 1988; Saltz, 1988; Saltz and Donnenwerth-Nolan, 1981); creating visual images of an interaction between a pair of objects in which one object serves as the cue for recalling the other object (Neisser and Kerr, 1973); or a "location mnemonic" in which each word-to-be-remembered is visualised at one of several locations on an imagined walk through a university campus (Baddeley and Lieberman, 1980).

Similar types visual-spatial imagery mnemonic strategies have been used since the time of the ancient Greeks. Many of these utilise a large group of imagined spatial locations (eg. rooms in a building). An image of each item-to-be-remembered is visualised as being at each of the locations. During recall the Subject simply imagines a walk through the building and recalls the image present at each of the locations. A variety of these memory strategies have been reviewed by Bower (1970a), Yates (1966), and Paivio (1979, pp. 153-175).

APX. V.130 Spatial Image Transformations.

In many experiments a spatial image (typically visual-spatial) must be mentally manipulated or transformed (eg. rotated, reflected, or scanned across) in order to answer some question about it. In Shephard and Metzler's (1971) classic example Subjects judged whether two similar abstract geometric figures in different orientations have the same shape or not. This task was used by other researchers (Bethell-fox and Shepard, 1988; Cooper, 1975; Cooper and Podgorny, 1976; Cooper and Shepard, 1973; 1984).

Other examples of spatial image transformations include judging whether a manikin is holding a particular object in its right or left hand while the manikin is presented upright, upside-down, front view, or rear view (Farmer et al., 1986); mentally rotating a cross-shaped matrix containing three objects and then verbally stating the new spatial relations (Brooks, 1970); scanning a visual image of an abstract line diagram and categorising the location of each corner (Baddeley et al., 1975; Brooks, 1968); judging if two rectangles (in different orientations and different sizes) are the same or different shapes (Sekuler and Nash, 1972); decide if three buildings (or U.S.A. states) are presented in their correct or a rotated and reflected arrangement (Evans and Pezdek, 1980); or imagining a visual scene, and then "zooming in" to answer questions about individual parts of the scene (Byrne, 1974). Image transformations are sometimes also required when making ideomotor localization judgements (see APX V.80), for example, making direction judgements while imagining oneself to be in a different location in the room, or that the entire room is rotated (Hardwick et al., 1976), imagining oneself to be facing a particular orientation and then indicating the direction towards another imagined location (Hintzman et al., 1981).

APPENDIX VI

KINESTHETIC-MOTOR MECHANISM IN SPATIAL ADAPTATION

A kinesthetic-motor mechanism in spatial perception is evident in the phenomenon of "adaptation to displaced vision". Kinesthesia and efference appear to be at the basis for correlating spatial perception across the different perceptual-motor systems (ie. vision, audition, kinesthesia).

Rock and Harris (1967) present several drawings which are illustrative of experiments using displaced vision (Fig. APX. VI-1). For example, in normal spatial behaviour a person who sees an object can also point (without vision of the arm) towards the object. When special glasses are worn, so that Subjects are looking through prisms which shift the optical image 15° to the right, initially the pointing movement (without vision of the arm) will correspond to vision and thus also point towards a location 15° to the right of the actual object. When vision of the pointing arm is allowed this error becomes evident to the Subject. The arm is not pointing at the object. While watching the movement of one's arm, the Subject gradually "adapts" so that the arm is again pointing at the visually perceived location of the object. That is, the kinesthetic stimulations arising from the arm are reinterpreted so as to correspond to the (displaced) visual stimulations. After adaptation (in as little as three minutes) the arm can again correctly point at the object (without vision of the arm).

When the prism-glasses are removed after adaptation the visual field will be shifted 15° to the left (back the original location for normal vision). However, kinesthetic stimulations from the arm will still be interpreted according to the displaced vision and so the pointing motion (without vision of the arm) will be 15° to the left of the actual object. When vision of the arm is allowed this error becomes apparent and adaptation occurs again until the arm can accurately point at the location of the object (Rock and Harris, 1967).

Perceptual-motor adaptation to displaced vision is extremely robust. For example, after adapting to prisim-glasses which induce a right/left reversal of the visual field Subjects will write numbers and letters backwards (corresponding to the visual reversal) without even being aware they are doing so (Rock and Harris, 1967).

Gibson (1966, p. 122) describes that "when prolonged abnormal information is imposed on a perceptual system" it will recalibrate itself so that kinesthesia and vision will "read" the same, thus reestablishing a "normalizing of skeletal space perception". Moulden (1971) interprets adaptation effects according to a "cue-discrepancy hypothesis" whereby adaptation occurs when a non-correspondence is experienced between two different perceptual systems (usually visual and kinesthetic). When spatial cues are discrepant then the perceptual systems adapt, or recalibrate, so that the discrepancy is no longer experienced.

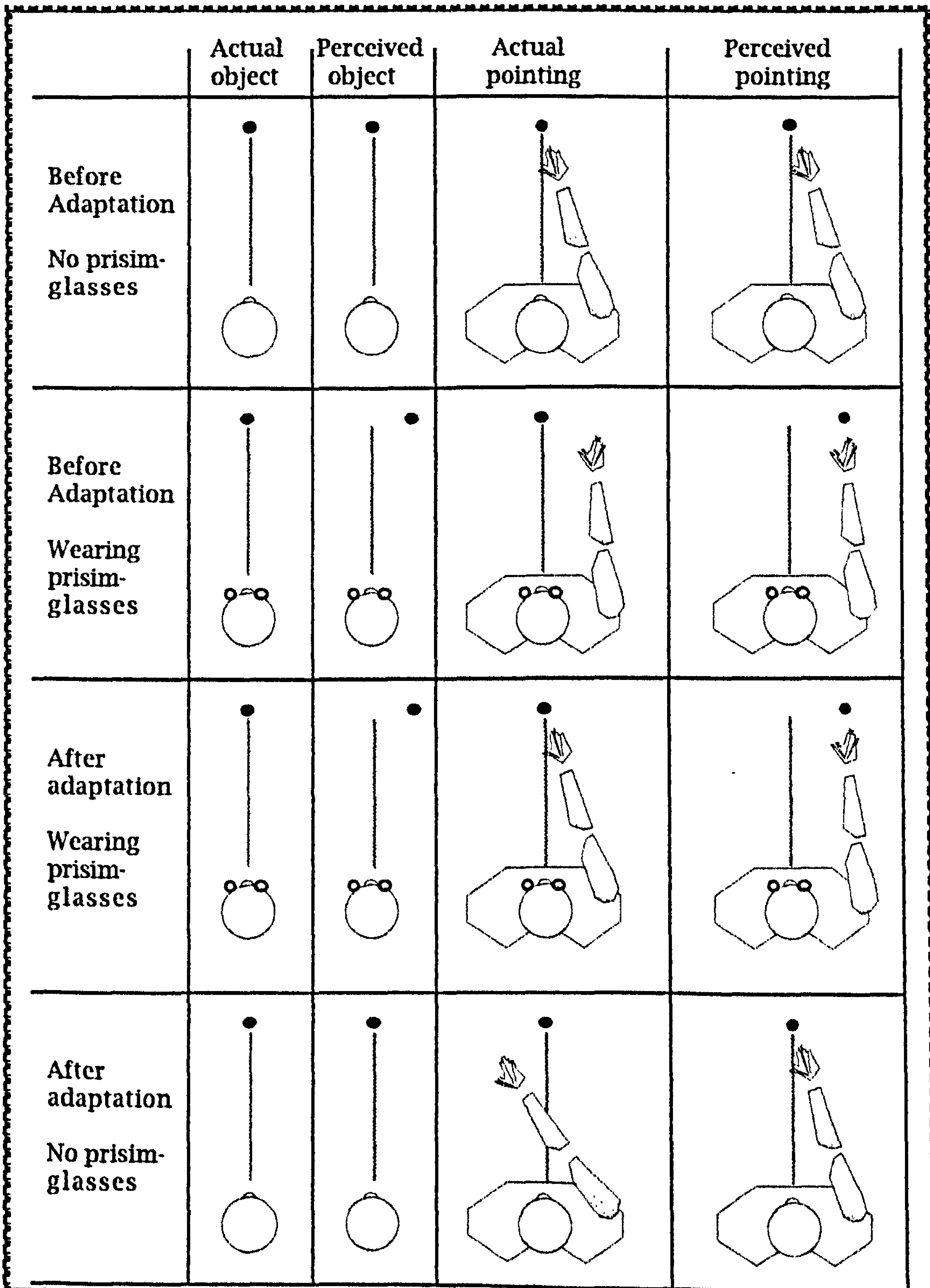

Figure APX. VI-1. Pointing (without sight of the arm) toward a visual object; with and without prism-glasses; before and after adaptation (adapted from Rock and Harris, 1967, p. 101).

This ability of perceptual-motor systems to adapt can be referred to as "plasticity". Perceptual-motor plasticity is likely to be important during the development of infants' initial spatial calibration amongst the different perceptual systems and would continue to be important as the body grows since larger and heavier body-parts would produce different kinesthetic sensations and motor commands would need to be modified to accomplish the same spatial goal (Held, 1968). Perceptual-motor plasticity would also be important for the control of spatially directed movements in novel environments where physical factors acting on the body are altered (thus producing different kinesthetic sensations), such as underwater or in zero-gravity (Held and Freedman, 1963).

The adaptation to discrepant spatial information appears to be based on a kinesthetic mechanism. This is indicated since adaptation is specific to the body-parts which have moved in the visual field during the adaptation period. For example, if the right arm is held still while the left arm moves within a displaced visual field, then (after adaptation) when both arms point at a visual object (without vision of either arm) each arm will point in a different direction (Rock and Harris, 1967, p. 101). Likewise, if only the hand is allowed to move (wrist articulation) during adaptation to displaced vision, then the hand will demonstrate adaptation effects but the forearm (elbow articulation, which was held still during the adaptation period) will not (Putterman et al., 1969).

After adaptation, kinesthetic feedback appears to be interpreted in a new way to correlate with the (displaced) visual input. The shift in pointing will occur whether the Subject is pointing to a visual object, a sound source, or towards "straight ahead" (Rock and Harris, 1967). Subjects perceive that their head and eyes are facing forward when actually they are turned to the side the same degree as the prismatic visual displacement (Lackner, 1973; McLaughlin and Webster, 1967). For example, the combination of the head or eyes turned 15° left, and prismatic visual displacement 15° right, yields a perception of seeing straight forward.

Adaptation can also occur entirely within the kinesthetic perceptual-motor system. Kenny and Craske (1981) demonstrated that when the finger of one arm taps the other arm, a kinesthetic discrepancy (created by a mechanical apparatus which transfers the pressure of the touch 12.7 cm. closer to the body) is noticed at first, but after adaptation the two locations are perceived to the the same. They call this the "kinesthetic fusion effect".

When active, voluntarily produced movements occur (with vision of the moving limb) then adaptation occurs in just a few minutes. However, when the movements are passively moved by the experimenter (also with vision of the limb) then adaptation is small, even after periods of half-an-hour (Held and Freedman, 1963; Held and Gottlieb, 1958; Held and Hein, 1958). Thus it appears that kinesthetic and efferent data associated with voluntary movement are necessary for the spatial calibration of the senses. Kinesthetic (afferent) stimulations arise as a result of voluntary (efferent) movements and so the "reafference hypothesis" posits that adaptation (ie. calibrating spatial information to "read" the same across visual, audio, and kinesthetic perceptual-motor systems) is dependent on voluntarily produced movement (Held and Hein, 1958; Moulden, 1971).

However it was found that voluntarily produced movement was not necessary for adaptation to occur but that when Subjects intentionally give attention to kinesthetic feedback (and its discrepancy with displaced vision) that adaptation will occur from observing (through displaced vision) a visually displaced object touching the Subject's skin (Howard et al., 1965), or observing reflexively induced movement elicited by a physiotherapy vibrator placed on the biceps muscle (Mather and Lackner, 1975).

Lackner (1977a) suggests that actively produced movements may tend to produce the greatest adaptation because during active movements greater amounts of kinesthetic information is available than during passive movements. For example, muscle spindle receptors have an increased response and efferent data is available during active movement but not passive movement (see Appendix II.43).

These adaptation effects indicate that kinesthetic information (including efferent data) serves as the basis for the calibration of spatial information across the different perceptual-motor systems.

APPENDIX VII

COORDINATIVE STRUCTURES

The original thoughts on coordinative structures are usually credited to the famous Soviet physiologist N. A. Bernstein who's writings from the 1930s onward have led the way to a conception of motor control that can be called "The Bernstein Perspective" (Fitch et al., 1982; Tuller et al., 1982; Turvey et al., 1982) and has received recent reattention (Whiting, 1984).

APX. VII.10 Coordinative Structures, Synergies, Kinematic Chains

Bernstein (1984 [1935]) observed that muscles automatically cooperate during movement and referred to these as "structures of movements", "integral formations" or "integration of movements" which is "The most important feature implied by 'motor co-ordination'" (p. 83). The term "coordinative structure" was used by Easton (1972), and later by many others. It describes "a group of muscles often spanning a number of joints that is constrained to act as a single functional unit" (Kugler et al., 1982, p. 60), "a group of muscles functioning cooperatively together" (Turvey, 1977, p. 219), "functional synergies" (Sheridan, 1984b, p. 49), "functional groupings of muscles", "synergies", "muscle collectives", or "muscle linkages", or as, "a group of muscles whose activities covary as a result of shared efferent or afferent signals" (Kelso et al., 1979a, pp. 229-235).

The meaning of "synergy" is described as having "become very generalized, if not actually ambiguous" (Rasch and Burke, 1978, p. 47) and for some authors "because of this inconsistency, the use of the term has purposely been avoided" (Wells and Luttgens, 1976, p. 41). Synergy is often used to refer in a general way for any "functional grouping of muscles that act as a single unit" (Smyth and Wing, 1984, p. 305). More specifically, two basic types of synergy can be distinguished: Two (or more) muscles may "act as helping synergists to each other as they counteract or neutralize each other's undesired secondary action" or a "true synergy occurs when one muscle contracts statically to prevent any action in one of the joints traversed by a contracting two-joint or multi-joint muscle" (Rasch and Burke, 1978, pp. 47-48).

An often analogous concept is the "kinematic chain" (Bernstein, 1984, p. 82), or "kinematic linkages" (Turvey, 1977, p. 219) used to refer to a group of body segments and joints linked in a series. "An appendage such as an arm or a leg is a biokinematic chain -- that is, it consists of several connected links, so that a change in an one link affects the other links" (Turvey et al., 1982, p. 248). A kinematic chain can refer to the linkage of body-segments without specifying the degree to which the muscles have been coordinated into functional units. However, the presence of a kinematic chain implies some amount of coordination.

Similarly, Bartenieff and Lewis (1980, pp. 21, 105) refer to a "kinetic muscular chain" which exhibits an active coordination within the linkage, described as being "connected". They consider this to be the "body" aspect which is the necessary complement of the "spatial" aspect of choreutics.

Bernstein (1984, p. 91) describes movement "coordination" as having the qualities of "homogeneity, integration and structural unity". One of the simplest examples of the "integration of movements" is the "gradual transfer of innervation" within a muscle collective:

> The simplest and most easily observed phenomenon in this category [of integrated, coordinated movement] is the appearance of gradual and smooth redistribution of tensions in muscular masses, which is particularly clearly expressed in cases of phylogenetically ancient or highly automatized movements. A muscle never enters into a complete movement as an isolated element. Neither the active raising of tension nor the . . . inhibition in antagonistic subgroups is, in the norm, concentrated in a single anatomical muscular entity; rather, there is a gradual and even flow from one system to others. (Bernstein, 1984, p. 83)

Bartenieff and Lewis (1980, p. 247) give a similar example of the even gradation of rotary articulation throughout a a circular arm movement. Bernstein's gradation of innervation is also similar to Laban's law of "flowing-from-the-centre":

> . . . allowing the movement to flow out from the centre of the body. Such an arm-movement then has the sequence: torso impulse, leading of the shoulder blade, upper-arm, fore-arm, and lastly the hand. This movement comes out from the body-centre and ensures a light volatility. (Laban, 1926, p. 18)

APX. VII.20 Reflexes as Basis for Coordinative Structures

Turvey (1977, pp. 219-220) speculates that the reflex movements are the "'basis'" of the "functional groupings" of muscles since: 1) Reflexes do not function in isolation but also function in higher-order groups; 2) Reflexes involve complex body-use configurations which can be induced by simple stimulations; and 3) Reflexes can be manipulated to fit various situations. Therefore, the concept of coordinative structures includes both individual reflexes, and also "functional combinations of reflexes". This provides the basis for larger collectives of muscles which function as a single unit automatically adjusting within itself and to the exterior environment, rather than needing to be controlled as individual components.

Easton (1972, pp. 591-594; also 1978) refers to peripheral reflexes as "basic coordinative structures" which are "underlying all volitionally composed movements". Reflexive movements are characterised as a "library" of basic movements which can be utilised during volitional movement. This leads to the "hypothesis that the muscles engaged in associated movements are functionally connected by reflexes"; and that "the basic units of the language [of movement] are contractions of functionally related sets of muscles, of synergies, or are, very possibly, the reflexes". Thus, volitional movement is composed of "complex reflexes", which are composed of simpler reflexes. When greater effort is required for a movement, then "reflex recruitment" elicits more reflexive action within the muscle collective, analogous to motor neuron recruitment which elicits the contraction of more muscle fibres within a single muscle.

In an example by Hellebrandt and Colleagues (Hellebrandt et al., 1956; 1962; Hellebrandt and Waterland, 1962) Subjects lifted a load by flexion or extension of the wrist. The force exertable by the wrist (work output) can be increased or decreased by evoking (or not) a tonic neck reflex (by voluntary head/neck rotation or flexion). When a load is lifted by wrist flexion more force can be exerted by rotating the head away from the working arm or by flexing the head forward. If the load is lifted by wrist extension then more force can be exerted by rotating the head towards the working arm or extending the head towards the back. After Subjects were fatigued they were observed to spontaneously use reflexive postures of the head and other limbs to contribute to force production for the lifting task. This gives an example of how the configuration of the entire body will adapt to the actions of its parts according to reflexive patterns.

Fukuda (1961) identified the actions of many reflexes within postures in archery, baseball, dancing, diving, fencing, gymnastics, high jump, judo, shot-put, soccer, and sumo wrestling. It was often observed that the exterior form considered the most ideal or most efficient uses patterns of full-body reflexive organisation.

During breathing, the "biokinematic linkage" of head to spine should cause the head to move during breathing, but because of the "functional grouping" of muscles, the head is held still. During an inhalation the thoracic spine pushes backwards and this is compensated for by just the right amount of movement forward by the cervical spine and the pelvic girdle so that the head and the pelvis remain stationary (Gurfinkel et al., 1971b; Tuller et al., 1982, p. 254).

APX. VII.30 Reducing Degrees of Freedom

The problem of "degrees of freedom" is that there are too many independent parts of the body to control separately during movement. The use of reflexes to organise functional groupings of muscles allows a "strategy of partitioning degrees of freedom" so that they are "constrained" or "dissipated" in a hierarchical control structure, that is, an "equation of constraint" governs the relationship by which two of the individual units will act in cooperation.* A motor command is given to an entire higher-order linkage (eg. the arm) and the lower-order individual units (single muscles) carry out the details (according to practiced reflexes) without any higher-order control.

Muscle collectives simplify the degrees of freedom problem because rather than controlling a large number of individual muscles, these are organised into a small number of higher-order groupings of muscles. A muscle collective accomplishes "a systematic linking together of muscles in such a manner that the set of individual muscles is reduced to a much smaller set of muscle collectives" (Kugler et al. 1982, p. 60).

APX. VII.40 Coordinative Structure Hierarchy

At a very basic level are simple reflexes such as the mono-synaptic stretch reflex which governs the reaction of a single muscle to a stimulus, and reciprocal inhibition which governs the tension/release relation between pairs of opposing muscles. At more complex levels are patterns of action within an entire limb, for example during the withdraw reflex and startle reflex. Then there are relations across different limbs such as in the crossed-extensor reflex. At the highest level the production of full body configurations are produced, for example during righting reactions. Many of these reflexive patterns have been organised into a developmental framework by Cohen (1989a; 1989b).

For example, Kelso and Colleagues (1979a; 1979b) observed that both arms were constrained to act as a a unit when reaching for two separate targets

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* The reduction of degrees of freedom in coordinated structures is cited by Jordan and Rosenbaum (1989, pp. 730-732), Kugler and Colleagues (1982, p. 6), Saltzman (1979), Tuller and Colleagues (1982, p. 254), Turvey and Colleagues (1982, p. 245).

simultaneously. The overall speed of the "easy" movement (ie. a nearby large target) slowed down so that it began and ended moving at the same time as the more "difficult" movement (ie. a distant small target). The two arms were constrained to begin and end moving at the same time, and thus to reach peak velocity and peak acceleration at the same time (though the overall speed and overall force produced by each hand/arm was different). Thus, while each arm reached for a different target, the two arms were also constrained to act together as revealed by their identical timing.

APX. VII.50 Tuning the Coordinative Structure

Coordinated reflexive movement does not mean there will always be the same fixed "knee-jerk" response to a particular stimuli. Rather, the responses of reflexes and groups of reflexes allows adaptation and adjustment to variable conditions. This is sometimes termed "tuning" the coordinative structure (Fitch et al.,1982).

Jordan and Rosenbaum (1989, p. 732) distinguish two possibilities: "Fixed linkages" refers to actions of muscles which are "hardwired" together and include the most basic reflexes in which the action of one muscle always evokes the reaction of another muscle (eg. reciprocal inhibition). "Soft linkages" are more flexible are refer to adjustable reflexes in which a stimulation will evoke a reaction only in a particular situation. These soft muscle linkages can be learned and adapted to fit specific occasions.

However, according to the "principle of higher-level modulation of spinal reflexes" even the so-called "hardwired" reflexes (eg. mono-synaptic stretch reflex, reciprocal inhibition) can be tuned in accordance with particular tasks (Turvey, 1977, pp. 323-233). For example, after Monkeys were trained to grasp a handle and either release it or pull it. After this was well learned it was found that the Monkey's intention on what movement to do with the handle could either inhibit or enhance the stretch reflex. The reflexive responses at 12 msec and 30-40 msec were both adjusted according to the Monkey's planned movement. This evidence blurs the distinction between notions of "voluntary" versus "reflex" movements (Evarts, 1973; Evarts and Tanji, 1974). Likewise, the "wiping reflex" of the Frog exhibits many automatic adjustments to locations of stimuli and configuration of its body parts (Berkinblit et al., 1986). A great deal of physiological evidence also indicates that the spine does not simply reproduce neural instructions, but is itself responsible for a great deal of movement control (Gurfinkel et al., 1971a).

In another example of automatic adjustment during reflex movements, Kelso and Colleagues (1984) applied unexpected perturbations to the jaw during speech and observed that perceptible speech distortions did not occur because of task-specific compensation movements. While attempting to say one word a jaw perturbation would evoke a movement of the upper and lower lips, but while attempting to say another word the same jaw perturbation would evoke a movement of the tongue. They concluded that "although the adaptive reactions could be described as reflexive because of their speed, their mutability speaks against any fixed reflex connections", instead this behaviour is described as "task-specific coordinative-structures" (p. 830) or as a "task-specific functional unit" (p. 828).

Turvey (1977, pp. 218-230) summarises how higher-order control can give an overall directive or "action plan" which does not specify any precise muscular activity. At the higher levels of control the reflexive interactions across limbs are organised. At lower levels "autonomous lower centers" control the reflexes operating entirely within each limb. When learning a new motor activity the high-order control may have to temporarily attend to specific lower-order variables. But as learning proceeds, lower-order coordinations become more automatic and control shifts to higher-order variables. This is a shifting to more abstract levels of control, higher in the hierarchy. The mental representation is more and more abstracted away from the actual movement.

APX. VII.60 Mass-Spring System

A mass-spring system, taken as a model for motor control (see IIIB.20), is one type of coordinative structure by which many body-segments can be coordinated to function as a unit. This reduces the number of degrees of freedom to be controlled and utilizes automatic accommodations and adjustments provided by elastic properties of muscles (Jordan and Rosenbaum, 1989, p. 732; Tuller et al., 1982, p. 265). It is suggested that the oscillatory, spring-like behaviour of muscles may be more similar to "limit-cycle oscillators" which behave in a way just slightly different from mass-spring oscillators. When two or more limit-cycle oscillators have some sort of interaction while operating they may influence each other so that their oscillations behave as one. This behaviour is known as "mutual synchronization" or "entrainment" (Kugler et al., 1982; Tuller et al., 1982, p. 269). The typical example is Huygens' clocks:

> Huygens [observed] in the 18th century . . . that, when two clocks . . . running at different speeds were both hung on the same thin backboard, they became synchronized and kept identical time. Apparently, the ticking of one clock was transmitted through the thin backboard to the other clock, and vice versa, until eventually the two clocks synchronized. (Tuller et al., 1982, p. 269)

Entrainment behaviour may encourage separate spring-like muscle oscillations to integrate into larger collections, at the highest order the entire body functions as a single oscillatory system, every part compensating and accommodating for every other part without moment-by-moment control.

APX. VII.70 Conclusion

This brief introduction to coordinative structures reveals that the interactions between body-parts can be automatically coordinated through a "library" of reflexive movements during a higher-order task of reaching to a particular location with the distal end of a skeletal linkage. Because of this, coordinative structures can be seen as an essential "body"-level counterpart to the "spatial"-level of choreutics and the spatial location-based motor code (see IIIB).

APPENDIX VIII

TERMINOLOGY FOR CARTESIAN DIMENSIONS AND PLANES

The "x", "y", and "z" axes of the Cartesian coordinate system and the corresponding three "Cartesian planes" ("xy" plane, "yz" plane, "zx" plane) are used in anatomy and kinesiology to specify the locations and movements of body-parts. The three Cartesian axes (ie. dimensions) and three Cartesian planes have been referred to with various terms. These may create confusion because the same term might describe different planes and also a dimension (eg. "vertical" see below). These terms will be briefly reviewed and terms used in this research will be designated.

When the Cartesian planes are conceived to pass through the body's centre of gravity then they are termed the "cardinal" planes. When they do not pass through the body's centre or gravity then they are specified by the location of the three planes central intersection point (eg. shoulder centred Cartesian planes) (Rasch and Burke, 1978, pp. 97-98; Wells and Luttgens, 1976, p. 20). Thus, each Cartesian plane might be described as passing through the centre of gravity, or as parallel to a central plane.

The human body and the bodies of many animals, display a reflection symmetry between their right and left sides. A plane can be imagined which passes through the centre of the body and exactly divides the right side from the left. The terms "median plane"* and "sagittal plane"# seem to be used synonymously as dividing a "bilaterally symmetrical animal into right and left halves" (American, 1982). Sometimes the term "midline plane" (Dempster, 1955, p. 581), "median sagittal plane" (Craske and Crawshaw, 1974b, p. 274), or "anteroposterior" plane (Wells and Luttgens, 1976, p. 20) are used. In other places the median plane is considered to pass through the centre while the sagittal plane is described as "dividing the body into *un*equal left and right parts and parallel to the median plane" (Kapit and Elson, 1977, p. 1 [italics mine]). Thus, a "mid-sagittal plane" (Dempster, 1955, p. 563; Dempster et al., 1959, p. 296; Howard, 1986, p. 3) would specify a sagittal plane passing through centre. In other places the sagittal plane is considered to either pass through centre or not (eg. Fitt, 1988, p. 21). Because it contains an up/down component this plane can also

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* "Median plane" is used by Howard (1986, p. 3), Kapit and Elson 1977, p. 1), Stelmach and Larish (1980, p. 169), and Wells and Luttgens (1976, p. 20)

\# "Sagittal plane" is used by Dempster (1955, p. 565), Dempster and Colleagues (1959, pp. 306-308), Dell (1970, p. 73; 1972, p. 7), Fitt (1988, p. 22), Kapandji (1970, p. 24), Preston-Dunlop (1980, p. 123; 1984, p. ix), Rasch and Burke (1978, p. 97), Saltzman (1979, p. 95), and Wells and Luttgens (1976, p. 20).

be referred to as a "vertical plane" (American, 1982; Barnes, 1963, pp. 260-261; Bodmer, 1979, p. 13; Schmidt and McGown, 1980, p. 155; Wells and Luttgens, 1976, p. 20). Within choreutics the term "wheel plane" is often used since this plane has the same orientation as a wheel.*

The term "median" comes from the Latin for "middle" and is used in English to refer to (for example) a statistical average, a dividing strip between opposing directions of traffic, as a verb (mediate) to refer to intervening and negotiating differences between conflicting parties to bring an agreement, or in any general reference of something being towards the middle (American, 1982; Collins, 1986).

The term "sagittal" comes from the Latin for "arrow" and is used in anatomy to refer to the sagittal suture (the joint between the two parietal bones lying on a forward/backward line across the top of the skull) or in reference to anything parallel to the sagittal suture (American, 1982; Collins, 1986).

The term "sagittal" is also commonly used to refer to the forward/backward dimension.# When sagittal is considered to be a plane, then the dimension is sometimes referred to as the "sagittal horizontal axis" (Wells and Luttgens, 1976, p. 39).

The term "sagittal" will be used here only to refer to the forward/backward dimension. This is also closest to the Latin root of sagittal as an arrow. The term "median" will be used to refer to the plane. In the case of a non-central plane the term "paramedian" (ie. parallel to the median plane) can be used. The term "wheel plane" is descriptive but the idea of a wheel may introduce a bias towards the sagittal dimension at the expense of the up/down component of the plane.

Another plane separates the front of the body from the back. This plane is usually referred to as either the "frontal plane"ø or the "coronal plane".ç Howard

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* "Wheel plane" is used by Bartenieff and Lewis (1980, p. 31), Bodmer (1979, p. 13), Dell (1970, p. 73; 1972, p. 7), Moore (1982, p. 69), and Preston-Dunlop (1980, p. 123; 1984, p. ix).

\# "Sagittal" is used for the dimension by Bartenieff and Lewis (1980, p. 29), Dell (1972, p. 5).

ø "Frontal plane" is used by American (1982), Dempster and Colleagues (1959, pp. 292-296), Fitt (1988, p. 22), Kapandji (1970, p. 24), Kapit and Elson (1977, p. 1), Rasch and Burke (1978, p. 97), Saltzman (1979, p. 95) and Wells and Luttgens (1976, p. 20)

ç "Coronal plane" is used by Dempster and Colleagues (1959, pp. 291-296), Howard (1986, p. 3), Kapit and Elson (1977, p. 1), Rasch and Burke (1978, p. 97), and Wells and Luttgens (1976, p. 20).

(1986, p. 3) refers to the "mid-frontal plane" as equivalent with the "coronal plane", thus implying that the frontal plane does not necessarily pass through centre. Because of the up/down component this plane is sometimes referred to as a "vertical plane" (Dell, 1970, p. 73; 1972, p. 7; Wells and Luttgens, 1976, p. 20) and because of the right/left component it is sometimes referred to as a "lateral plane" (Fitt, 1988, p. 22; Wells and Luttgens, 1976, p. 20). In choreutics this plane is often referred to as the "door plane"* since it is parallel to the orientation of a closed door.

The term "coronal" comes from the Latin for "crown" and is used in English to refer to (for example) the ring visible around the sun or moon when they are viewed through a thin mist, the upper part of the head or coronal suture, a circle of light or halo, the coronary arteries which entirely encircle the heart, a garland, wreath, circlet, or crown as which might be used in a *corona*tion (American, 1982, Collins, 1986).

The term "frontal" comes from the Latin for "facade" (American, 1982) and "forehead" (Collins, 1986) and is used in English to refer to (for example) the frontal bone of the skull, the frontal lobe of the cerebral cortex (under the frontal bone), a forehead ornament, a frontal view in visual arts, the facade of a building, or an ornamental drapery over the front of an alter.

The term "vertical" comes from the Latin for "vertex" and is used in English to refer to being at a right angle to the horizon, upright, the highest point, and directly overhead. A "vertical circle" is defined as a circle which "passes through the zenith and the nadir and thus is perpendicular to the horizon (American, 1982). The idea of a vertex enforces how this term is primarily used to refer to the up/down dimension.

The term "lateral" comes from the Latin for "side" and is used in English to refer to (for example) anything relating to the sides, curling the tongue so that the air stream passes around its sides (eg. making the sound "L"), solving problems by employing unorthodox or seemingly illogical means, throwing the ball sideways in American football, and the difference between the right and left cerebral hemispheres (American, 1982; Collins, 1986).

Both the frontal and the horizontal plane contain laterality, and so sometimes the right/left dimension is referred to as the "frontal horizontal axis" (Wells and

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* "Door plane" is used by Bartenieff and Lewis (1980, p. 31), Bodmer (1979, p. 12), Dell (1970, p. 73; 1972, p. 7), Moore (1982, p. 69), and Preston-Dunlop (1980, p. 123; 1984, p. ix).

Luttgens, 1976, p. 39). The term lateral may be best suited to refer to the right/left dimension.

The terms "vertical" and "lateral" will be used here to refer to dimensions (Cartesian axes). The term "frontal" appears to be more appropriate for this plane since the Latin root for "coronal" describes the circular shape of a crown rather than a planar orientation. In cases where the plane specifically passes through the centre the term "midfrontal" can be used.

The other Cartesian plane perpendicular to the vertical dimension is typically referred to as the "horizontal plane"* or the "transverse plane",# though sometimes "longitudinal" plane is used (Saltzman, 1979, p. 95). In choreutics this plane is often termed the "table plane".ø Howard (1986, p. 3) implies that the transverse plane is not necessarily central and so the term "mid-transverse plane" is used to specify the central plane. In other places a "transverse plane" refers to any plane that cuts cross-ways through the long axis of the body but not necessarily oriented horizontally (Kapit and Elson, 1977, p.1).

The term "horizontal" comes from a Greek term for the boundary of a circle. The terms "horizon" and "horizontal" are used in English to refer to (for example) where the earth and the sky visually appear to intersect, the range of a person's knowledge experience or interest, occupying the same level in a hierarchy, uniformity or equality to all members of a group, a layer in soil or rock which has a particular composition, level, or anything parallel to the plane of the horizon (American, 1982; Collins, 1986).

"Transverse" comes from the Latin "to turn or direct across" and is used in English to refer to (for example) a line that intersects two or more other lines, crossing from sided to side, a transverse process (a sideward projection extending from either side of a vertebra), the transverse colon (part of the large intestine which runs sidewards around the front of the abdomen), the way a flute is held at right

* "Horizontal plane" is used by Dell (1970, p. 73; 1972, p. 7), Dempster and Colleagues (1959, pp. 306-307), Kapandji (1970, p. 24), Kapit and Elson (1977, p. 1), Preston-Dunlop (1980, p. 123; 1984, p. ix), Rasch and Burke (1978, p. 97), Stelmach and Larish (1980, p. 170), and Wells and Luttgens (1976, p. 20).

\# "Transverse plane" is used by Dempster and Colleagues (1959, pp. 291, 296), Fitt (1988, p. 22), Rasch and Burke (1978, p. 97), and Wells and Luttgens (1976, p. 20).

ø "Table plane" is used by Bartenieff and Lewis (1980, p. 31), Bodmer (1979, p. 13), Dell (1970, p. 73; 1972, p. 7), Moore (1982, p. 69), and Preston-Dunlop (1980, p. 123; 1984, p. ix).

angles to the mouth, or anything which is lying across or crosswise (American, 1982; Collins, 1986).

"Transverse" is also used in choreutics to refer to lines which cut across other lines. This notion of "cutting across" appears to be the essence of the term and it is used this way in geometry. Thus, this term will not be used here to refer to a plane.

The term "horizontal" will be used to refer to the plane and this seems close to its Latin root as the boundary of a circle. When the horizontal plane needs to be specified as passing through the centre, the term "midhorizontal" can be used. The term "table plane" elicits a vivid image but it creates an association of a plane at table-level whereas a horizontal plane could be on the floor, or high above the head.

The term "horizontal" is also used to refer to the right/left dimension.* This usage may have developed since when viewed from the front the horizontal plane is seen as a right/left line, thus, the horizontal dimension. However, any line perpendicular to the vertical (eg. the sagittal dimension or any other line in the horizontal plane) can be described as a "horizontal" line.# To avoid confusions the term "lateral" is used here to refer to the right/left dimension.

SUMMARY:

In this research the following terms for Cartesian axes (dimensions) and Cartesian planes will be used:

<u>Planes</u>:	
Medial	(or paramedial for a non-central plane)
Frontal	(or midfrontal for a central plane)
Horizontal	(or midhorizontal for a central plane)
<u>Dimensions</u>:	
Vertical	(gravity up/down or anatomical superior/inferior)
Sagittal	(anatomical anterior/posterior)
Lateral	(anatomical right/left)

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* "Horizontal" is used as a dimension by Bartenieff and Lewis (1980, p. 29), Dell (1970, p. 73; 1972, p. 5)

\# The sagittal dimension can be described as a horizontal line since it is perpendicular to the vertical (Barnes, 1963, p. 260; Preston-Dunlop, 1979).

APPENDIX IX

ANALYSIS OF "VECTOR SYMBOLS" AS USED IN CHOREOGRAPHIE

A group of notation symbols were used by Laban in his early German work Choreographie (1926). An analysis of the notations reveal that these symbols are used to indicate a specific directional orientation but not any particular location. Thus, they are referred to here as "vector symbols". An analysis of some of Laban's (1926) notations will support the vector-like interpretation of these symbols.

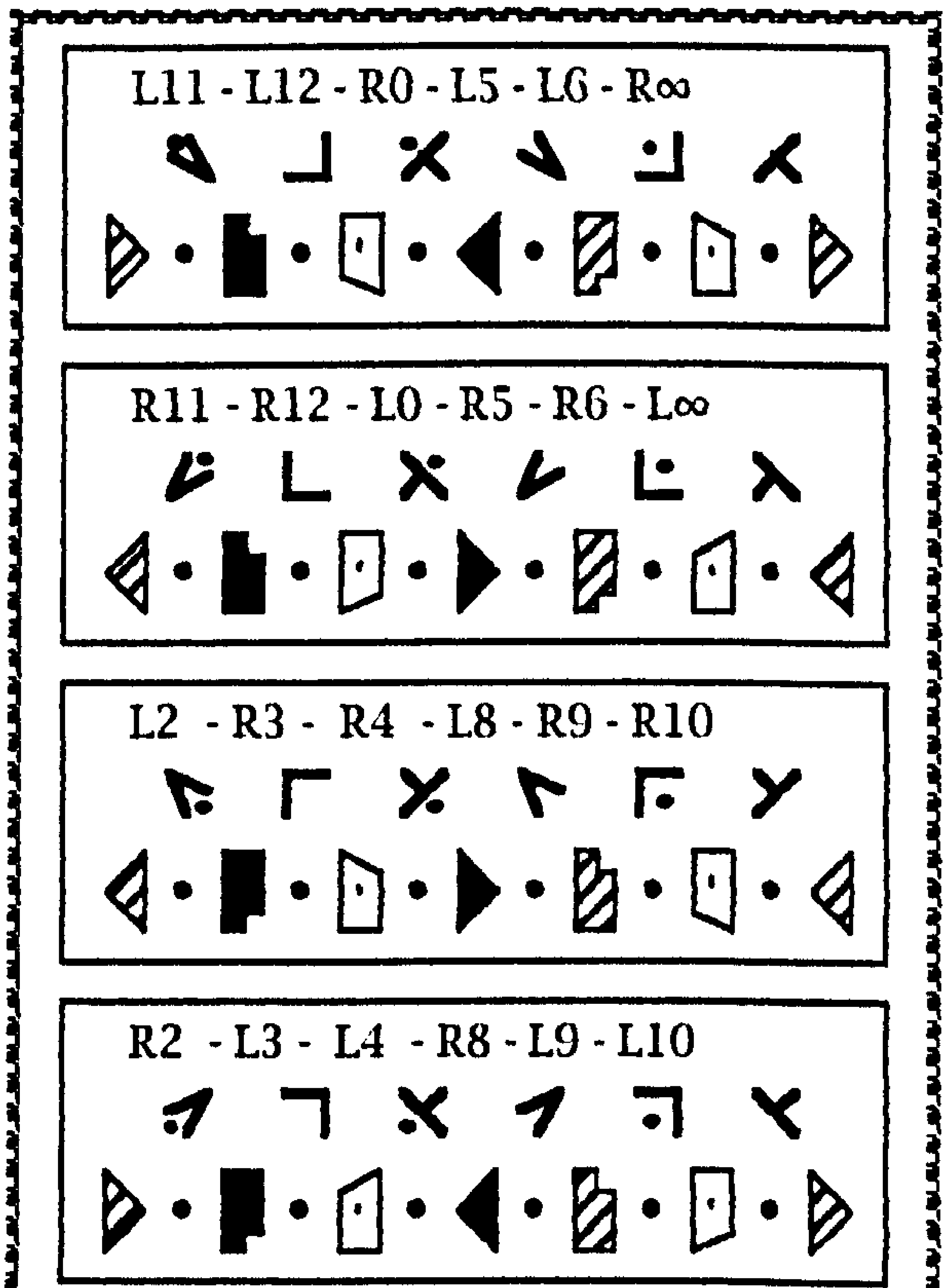

Figure APX. IX-1. Axis scales (adapted from Laban, 1926, p. 44).

Laban (1926, p. 44) lists the vector symbols together with the inclination numbers within the well-known sequences of the axis scales. The meaning of the inclination numbers can be verified in other places. They are based on the order of the inclinations in the right and left A-scale and the right and left B-scale (Laban, 1926, pp. 29-32; Ullmann, 1966, pp. 156-162). The axis scales, notated with the inclination numbers and vector symbols as presented by Laban (1926, p. 44), are presented together with their corresponding Labanotation direction-symbols in Figure APX. IX-1.

From these axis scale notations it could be hypothesised that each vector symbol has a one-to-one correspondence with an icosahedral transverse inclination from the A-scale and B-scale. This hypothesis can be tested on the notation titled

"Scales combined from primary-directions in four diagonals over all 24 directions"*
(Laban, 1926, p. 52).

Laban (1926, p. 47) notes that the notations are read from columns from the bottom to the top. The first column on page 52 can be taken as an example. For the first-half of the notation the translation of each vector symbol into a particular A-scale or B-scale inclination is perfectly satisfactory. However, in the second-half of the notation, this translation is no longer adequate (Fig. APX. IX-2). As an alternative, the vector symbols might be interpreted as indicating only the end-point of a particular inclination (rather than the entire inclination line) (Fig. APX. IX-3). This is also not a satisfactory translation for two obvious reasons. It results in two different vector symbols being translated into each icosahedral locus (since two different A-scale and B-scale inclinations end at each icosahedral location#) and, in this particular sequence, this translation is not as symmetrical as the one arrived at by the next alternative.

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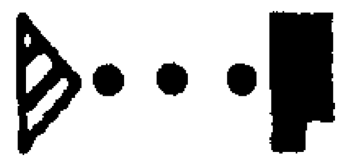
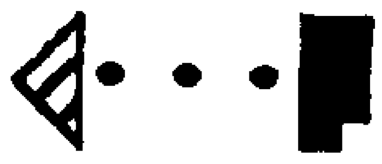
* "*Aus Hauptrichtungen kombinierte Skalen in vier Schrägen über alle 24 Richtungen*" (Laban, 1926, p. 52).

\# For example,  in the Right A-scale and the Right B-scale; and  in the Left A-scale and the left B-scale, both end at 

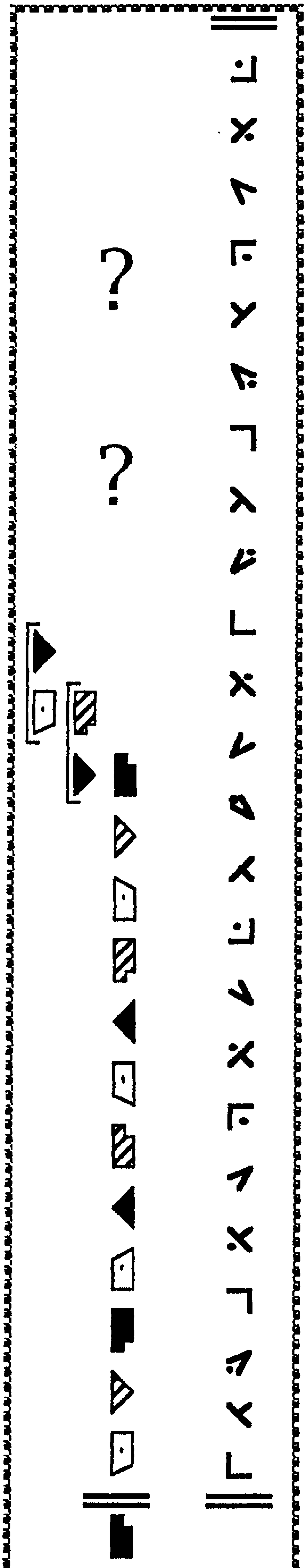


Figure APX. IX-2.

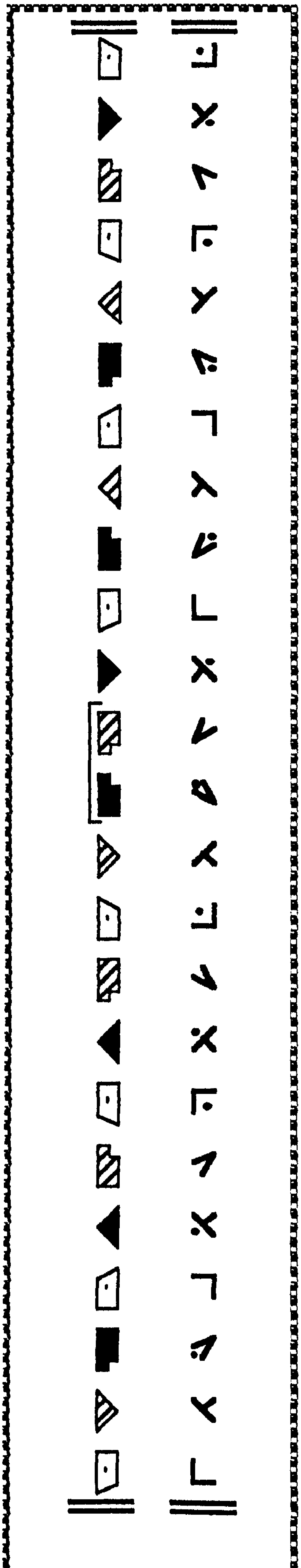


Figure APX. IX-3.

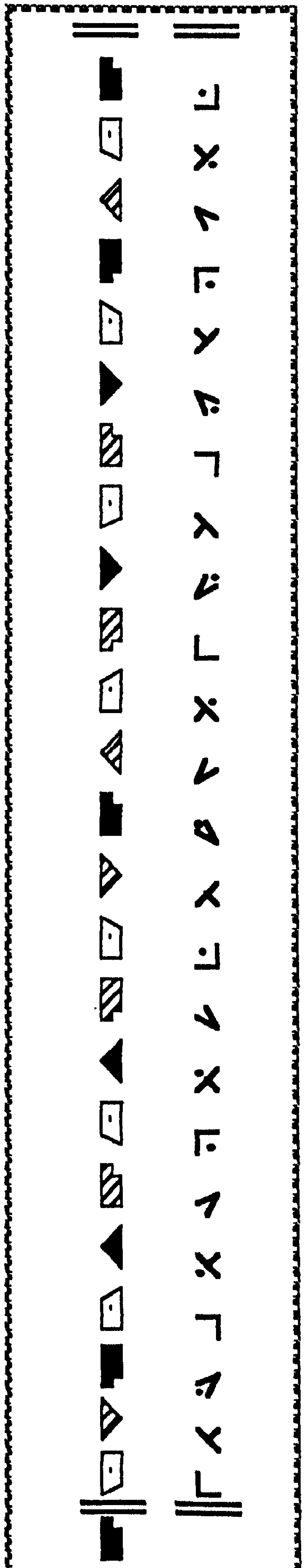
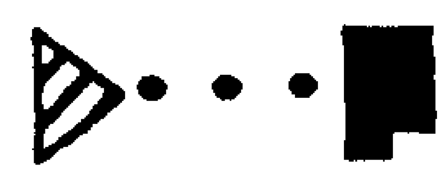
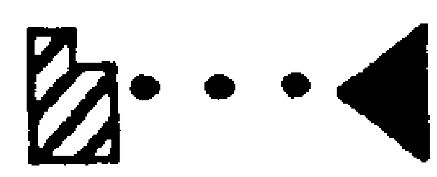


Figure APX. IX-4.

Another possibility for translating the the second-half of Laban's (1926, p. 52) notation can be derived by allowing the vector symbols to also be translated into inclinations progressing in "counter order"* (as opposed to the "natural order" of progressing through the Cartesian planes: frontal-medial-horizontal-frontal-etc.) (Fig. APX. IX-4). This translation yields a highly symmetrical spatial form in that it contains only inclinations (ie. not mixed with diameters) and it ends at the same place as it began. This is a typical characteristic of most of the choreutic scales (see Preston-Dunlop, 1984) and so supports the interpretation that this is the correct translation.

Thus, it might be hypothesised that the vector symbols refer to transverse inclinations in either the natural order or the counter order. According to this translation each vector symbol could be translated as either of two parallel transverse inclinations. For example:

 might be translated as  (natural order), or

 (counter order).

This translation is also evident in the notation titled "augmented three-rings or double-volutes with one action-swing-direction"ø (Laban, 1926, p. 72). A translation of the vector symbols solely into natural order inclinations proves to be unsatisfactory. However, when both natural order and counter order inclinations are used then a highly symmetrical and organised arrangement of "augmented three-rings" is derived (Fig. APX. IX-5).

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* "Counter order" (a term proposed by this author) is the reverse order as the one which Ullmann (1966) refers to as the "natural order of succession" (p. 152) which conforms to the spatial law of "compensation of extremes" (p. 149) whereby it feels "more comfortable, more pleasant" (p. 148) to begin steep inclinations from the (vertically stressed) frontal plane, to begin flat inclinations from the (laterally stressed) horizontal plane, and to begin suspended inclinations from the (sagittally stressed) medial plane. That is, "the most natural way is produced when the movements compensate the extreme extension of the plane from which they start" (p. 174). Whereas in the counter order (Ullmann calls these "inverted transversals" or "inverted inclinations") the movement "has, so to speak, to be taken by storm in order to overcome the resistance presented by the inverted inclinations" (p. 165).

The "natural order" yields a planar order of frontal-medial-horizontal-frontal-etc., and a sequence of inclinations progressing flat-steep-suspended-flat- etc. In contrast, the "counter order" yields a planar order of frontal-horizontal-medial-frontal- etc., and a sequence of inclinations progressing flat-suspended-steep-flat-etc.

ø "*Übermässige Dreiringe oder Doppelvoluten mit einer Ausschwungrichtung*" (Laban, 1926, p. 72).

The notation titled "Exercise for bodily practice. Scales assembled from short peripheral directions"# (Laban, 1926, p. 47) reveals that the vector symbols are also used for peripheral inclinations and peripheral dimensions. Additional symbols are used in this notation which are similar (although slightly different) to those introduced earlier as "trial-notation pure dimensions"ø (Laban, 1926, pp. 20-21) (Fig. APX. IX-6). Therefore, these additional symbols can be initially interpreted as referring to dimensions.

An initial attempt at translating the "scales assembled from short peripheral directions" into natural-order inclinations is partially adequate. However, the dimensional symbols will only fit logically into the sequence as locations, rather than as lines of motion (Fig. APX. IX-7). The alternative, indicated by the title of the notation, is to translate the vector symbols into peripheral inclinations. These are exactly parallel to the transverse inclinations used previously. In this case the dimensional symbols can also be logically be translated into dimensionally oriented lines (rather than points). The result is a highly symmetrical sequence which ends at the same location as it began and so appears to be the correct translation (Fig. APX. IX-8).

"*Köperlich auszuführende Übung. Aus kurzen peripherischen Richtungen zusammen-gesetzte Skalen*" (Laban, 1926, p. 47).

ø "*Schriftversuch Reine Dimensionen*" (Laban, 1926, p. 20).

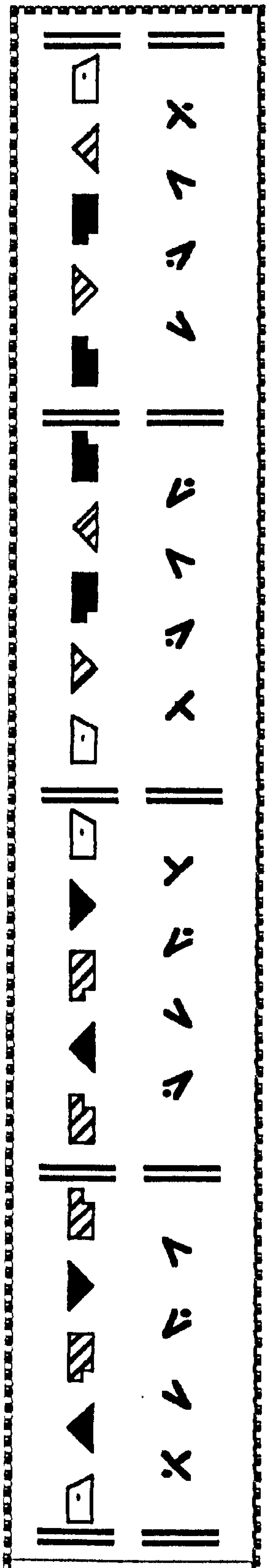


Figure APX. IX-5.

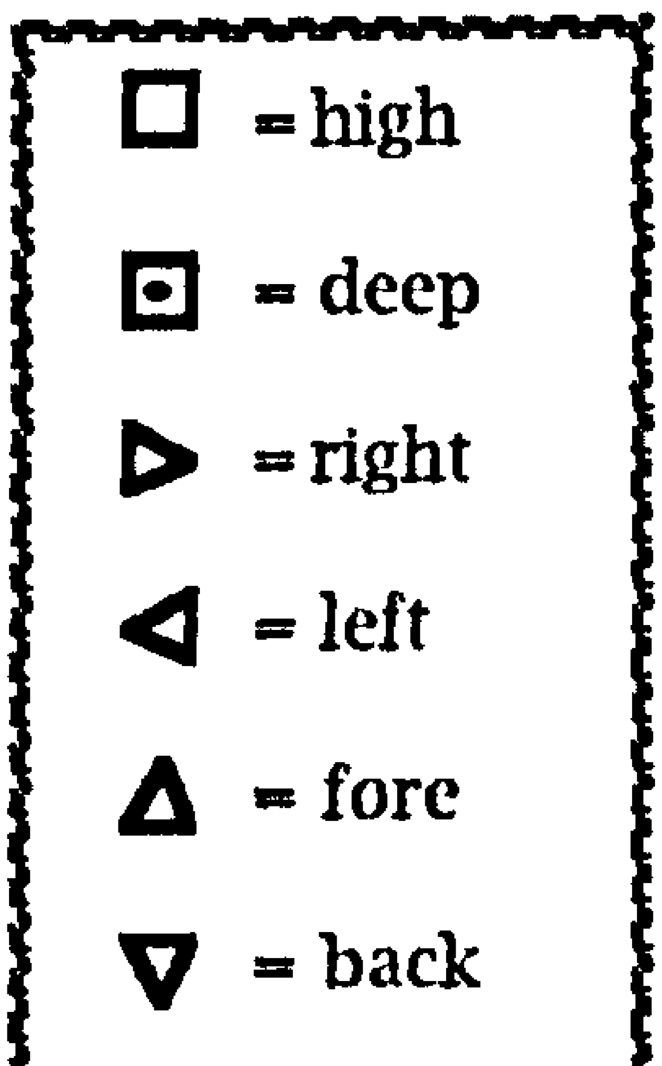


Figure APX. IX-6.

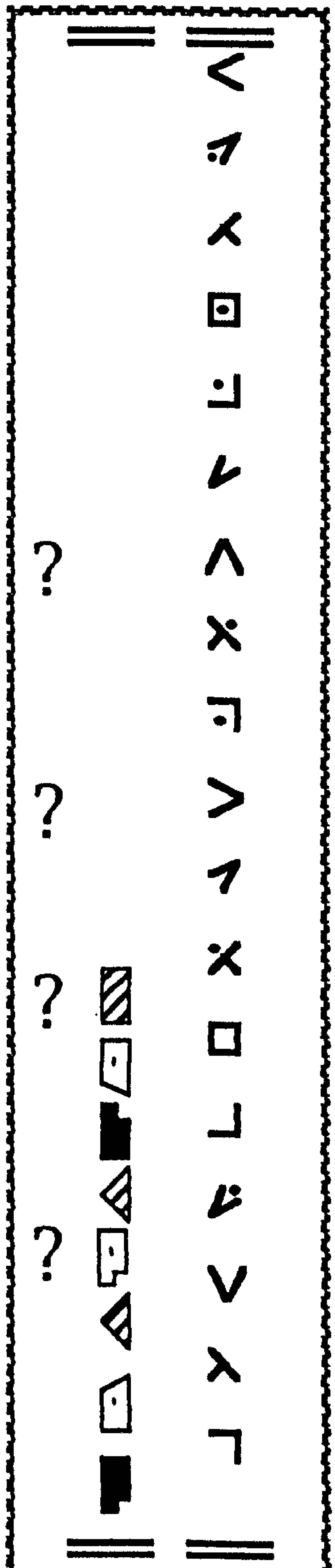


Figure APX. IX-7.

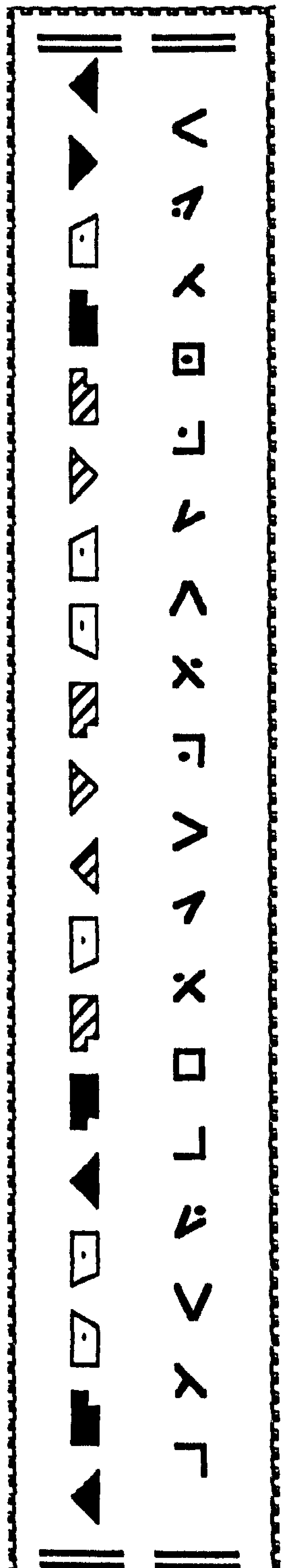


Figure APX. IX-8.

From this translation it is evident that the vector symbols are also used for peripheral inclinations which are parallel to the transverse inclinations. In addition, the dimensional symbols are used in a similar way to indicate a dimensionally oriented line, rather than a particular location, and so can also be considered to be dimensional vector symbols.

These examples indicate a translation scheme for the vector symbols. The vector symbols appear to be used to indicate the orientation of a line rather than the location of a point (thus, the term "vector" is proposed since these have directional orientation but no specific location). The vector symbols might be divided into inclinational vector symbols and dimensional vector symbols. Diagonal vector symbols can also be included since they have the same symbol structure (Laban, 1926, p. 21) even though they are not used in any of Laban's (1926) notations.

Laban (1926) uses the dimensional vector symbols only to indicate peripheral dimensions. However, since the inclinational vector symbols are used to indicate both peripheral and transverse inclinations it is consistent to allow the dimensional vector symbols to also indicate either peripheral or transverse dimensions.

The variety of possibilities for translation of the vector symbols into Labanotation direction symbols relative to the icosahedral network are presented in Figure APX. IX-9. This represents only the possibilities relative to the icosahedral network. The dimensional and diagonal vector symbols can also be expressed in Labanotation direction symbols relative to a cubic and an octahedral network.

By following the principal that a vector symbol refers to all parallel directions, regardless of their particular location, then many more (ie. infinite) possibilities for the particular location of each vector is allowable. Further variations in the particular location of a vector can be specified in Labanotation by varying the direction symbols with degrees of contraction, and intermediate directions (halfway points, third way points) (Hutchinson, 1970. pp. 166-170, 437-440).

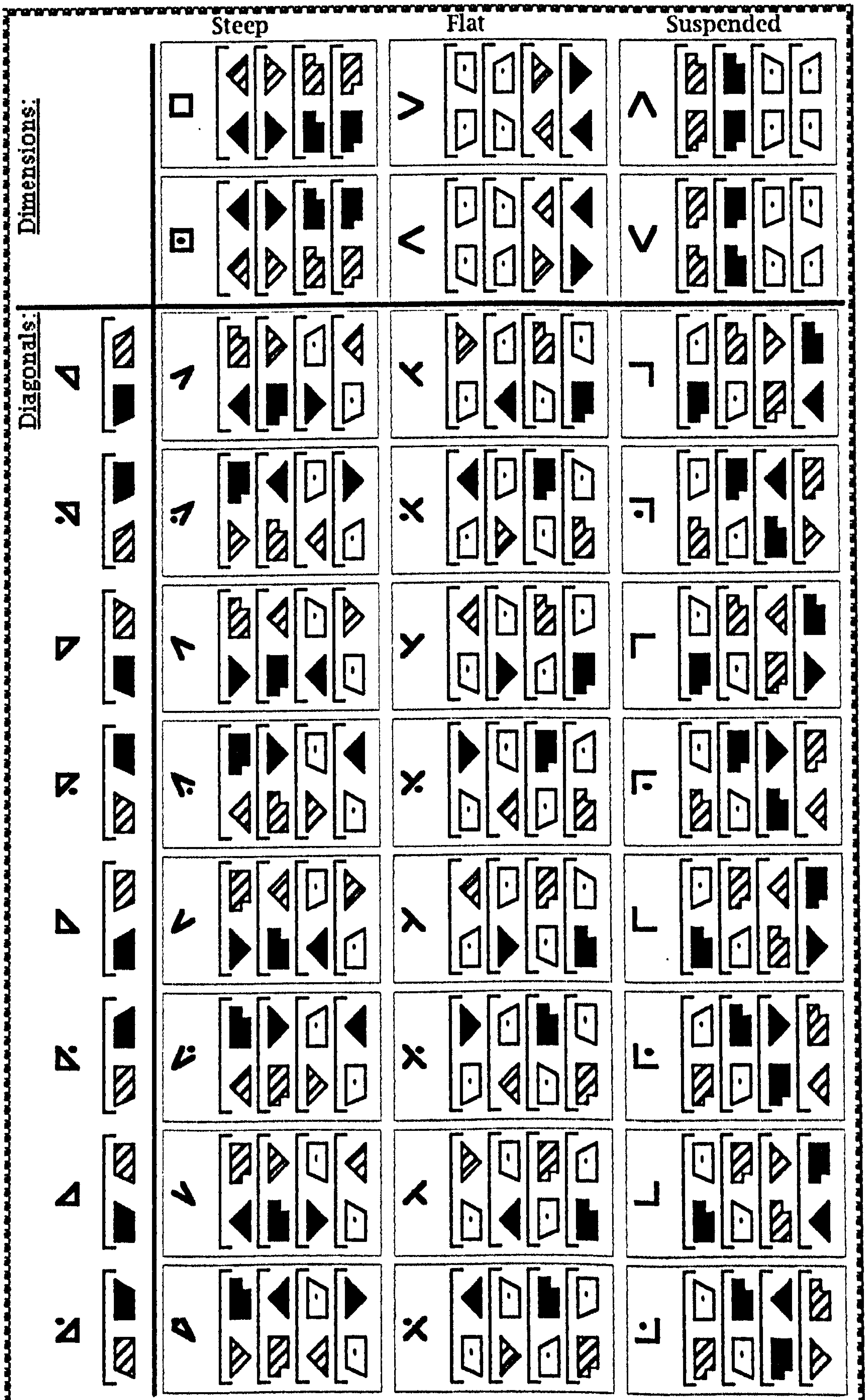


Figure APX. IX-9. Vector symbols translated into diagonals and icosahedral dimensions and inclinations (direction symbols in brackets are read from the bottom to top).

When the vector symbols are considered in their broadest definition, as freely translatable into any parallel direction regardless of the particular location, then they become virtually synonymous with Laban's (1966, pp. 125-132) notion of "free-inclination symbols" which are used to notate "free lines" and "free trace-forms". These free lines "may occur at any place, either inside or outside the kinesphere without being bound to the points of the scaffolding [ie. kinespheric network]" (p. 125). In this "free notation" a location is taken as the starting point, then the notation indicates only the distance and direction to be moved (relative to the vertical line of gravity) without regard to any particular locations (pp. 129-130). Laban (1966) mentions that this type of free notation is "an old dream in this field of [choreutic] research" (p. 125) suggesting how the early development of these vector symbols (based on the orientation of a line) (Laban, 1926) was later abandoned in favor of the conceptually simpler direction symbols (based on the location of a point).

When taken in an even broader sense, the vector symbols can be conceived relative to the "organic deflection hypothesis" (specified in this thesis; see IVA) which posits that dimensions and diagonals serve as conceptual prototypes for the deflected inclinations which are actually produced by the body. The dimensional and diagonal vector symbols can be considered to refer to the pure dimensional and diagonal orientations. Whenever the line of a movement or position deflects even slightly away from one of these pure dimensionals or diagonals then it can be considered to be an inclination and can be expressed with one of the inclinational vector symbols. In this broad sense an inclinational vector symbol can be used to refer to orientations which are approximately parallel (rather than exactly parallel). That is, the symbol  would refer to all steep (ie. vertical) deflections of the diagonal direction deep-back-left. Within this definition some variation of the precise orientation of the inclination would be allowed.

This broad definition of the vector symbols can be an additional valuable tool in the observation of human body movements and positions. Personal experience of this author has revealed that many movements do not join together particular locations within a conceptualised kinespheric network. The use of vectors frees the conception from a fixed network of points surrounding the mover and allows the observer to directly see the orientation of the motion or position.

APPENDIX X

ANGLES BETWEEN DIAMETERS AND DIMENSIONS

IN THE CUBIC, OCTAHEDRAL, ICOSAHEDRAL AND DODECAHEDRAL NETS

Laban conceived of various polyhedral networks surrounding the body according to which kinespheric paths and poses can be mapped. Cartesian planes can be identified within each of the polyhedral networks with four corners of a plane at four polyhedral vertices. Because of the different shapes of the cubic, octahedral, icosahedral and dodecahedral networks, the Cartesian planes will also have a particular shape.

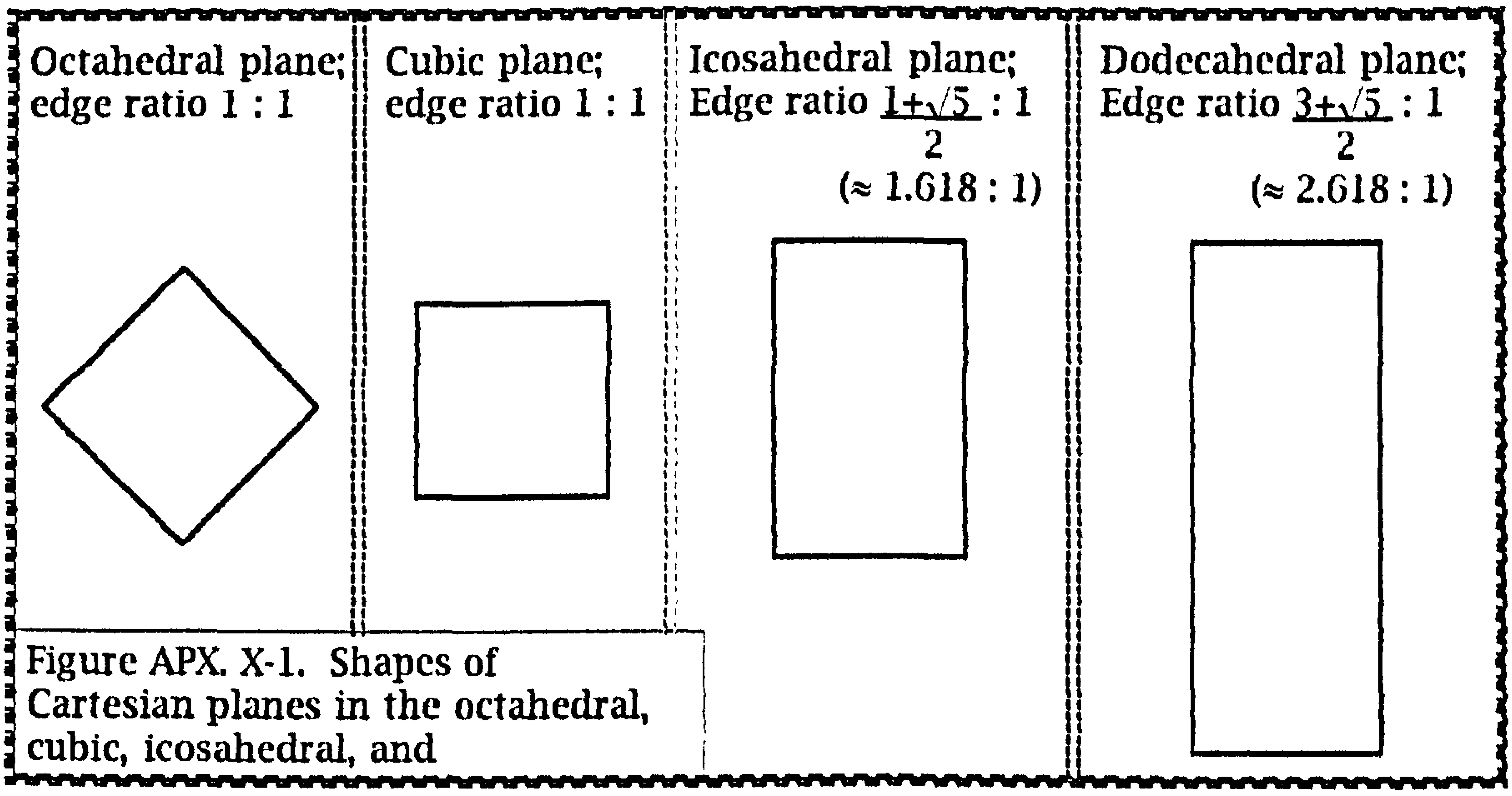
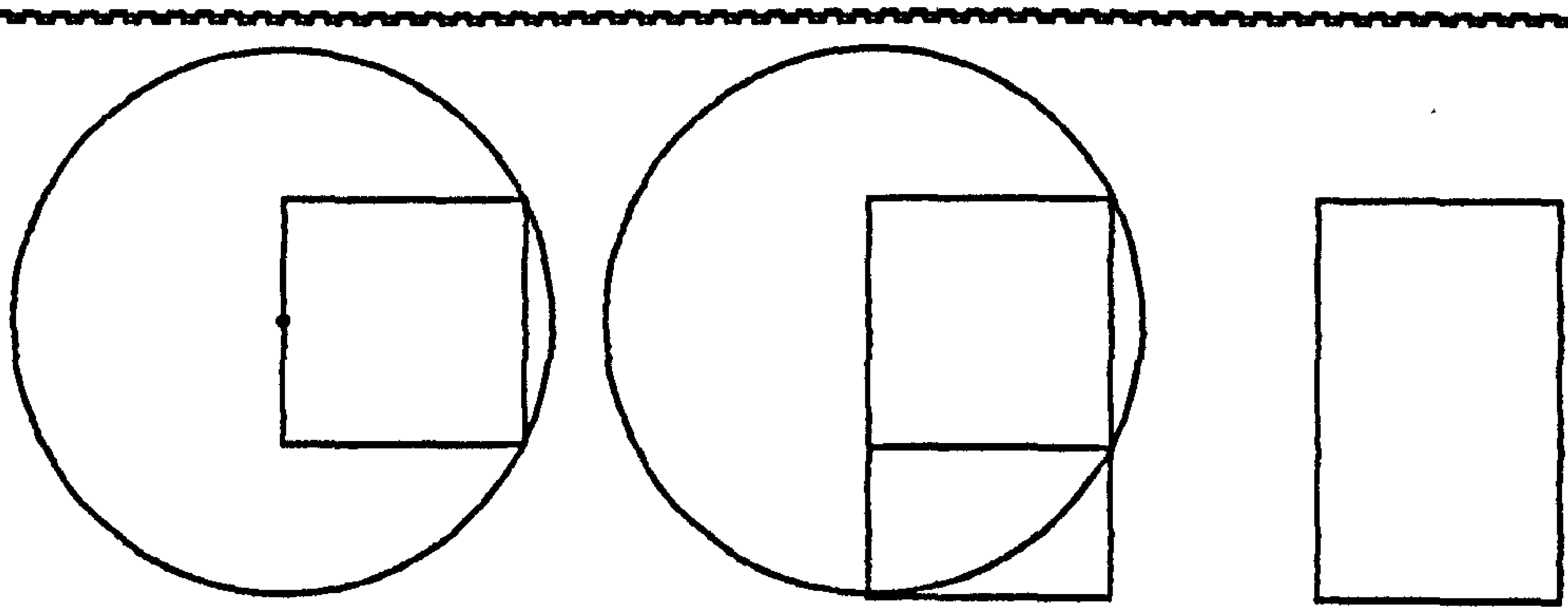


Figure APX. X-1. Shapes of Cartesian planes in the octahedral, cubic, icosahedral, and

The shapes of the Cartesian planes within each of the polyhedral nets commonly used in choreutics are pictured in Figure APX. X-1. The intersection of a Cartesian plane passing through a cube will have the shape of a square with a ratio between the length of edges of 1 : 1. The intersection of a Cartesian plane passing through the centre of a regular octahedron will have the shape of a diamond. This is the same shape as the square just rotated 45° and so the the ratio between the length of edges is also 1 : 1. The intersection of a Cartesian plane passing through the centre of a regular icosahedron will have the shape of a rectangle. The ratio of the length of the long edge to the short edge is part of an irrational proportion known as the "divine proportion" or the "golden section" (roughly 1.618 : 1) and so the rectangle is known as the "golden rectangle". The intersection of a Cartesian plane passing through the centre of a regular dodecahedron will have the shape of a long narrow rectangle in the shape of a golden rectangle plus one additional square. The ratio between the length of the long edge to the short edge is also part of an irrational proportion related to the golden section (roughly 3.618 : 1).

The method for constructing the golden rectangle is as follows (Ghyka, 1977): A circle is drawn with its centre at the midpoint of an edge of a square with the circumference of the circle intersecting two of the square's corners (Fig. APX. X-2a). The edge of the square which contains the circle's centre is then lengthened until it intersects the circumference of the circle. The length of the opposite edge is also lengthened the same amount and these two edges are connected to close the rectangle (Fig. APX. X-2b). Finally, the edge of the original square which now lies inside the rectangle is removed, thus completing the golden rectangle (Fig. APX. X-2c).



A): Circle concentric with mid-point of square's edge. B): Closed rectangle. C): Golden rectangle.

Figure APX. X-2. Constructing the golden rectangle (see text for explanation).

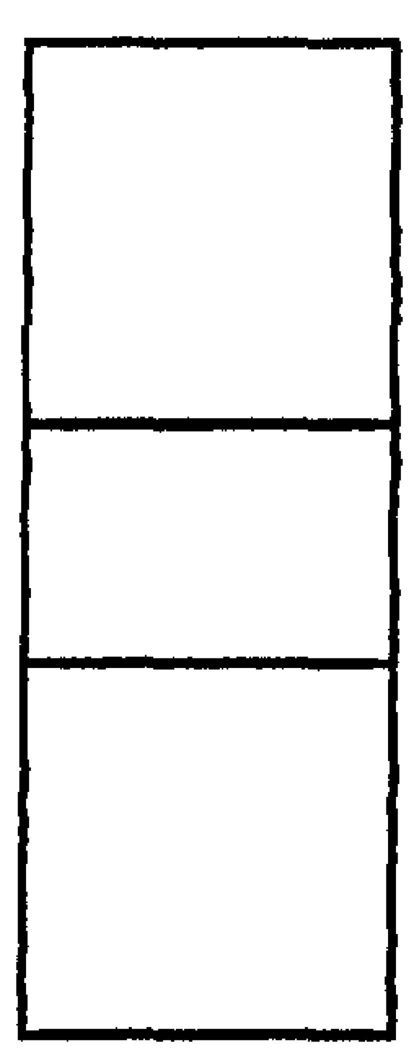


Figure APX. X-3. Golden rectangle + 2nd square

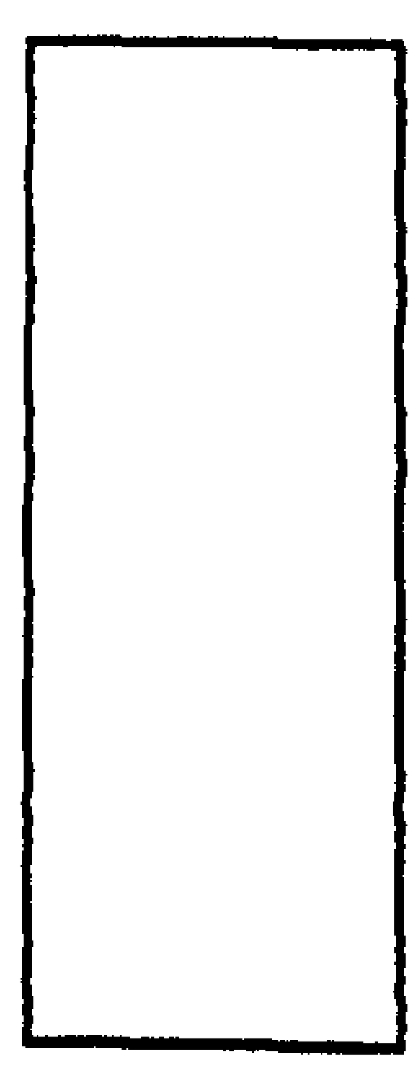


Figure APX X-4. Dodecahedral rectangular plane

The plane through the dodecahedron is constructed by simply adding another square onto the end of the golden rectangle (Fig. APX X-3) and then removing the interior lines (Fig. APX. X-4). This can be determined from Euclid's construction of the dodecahedron in The Elements.

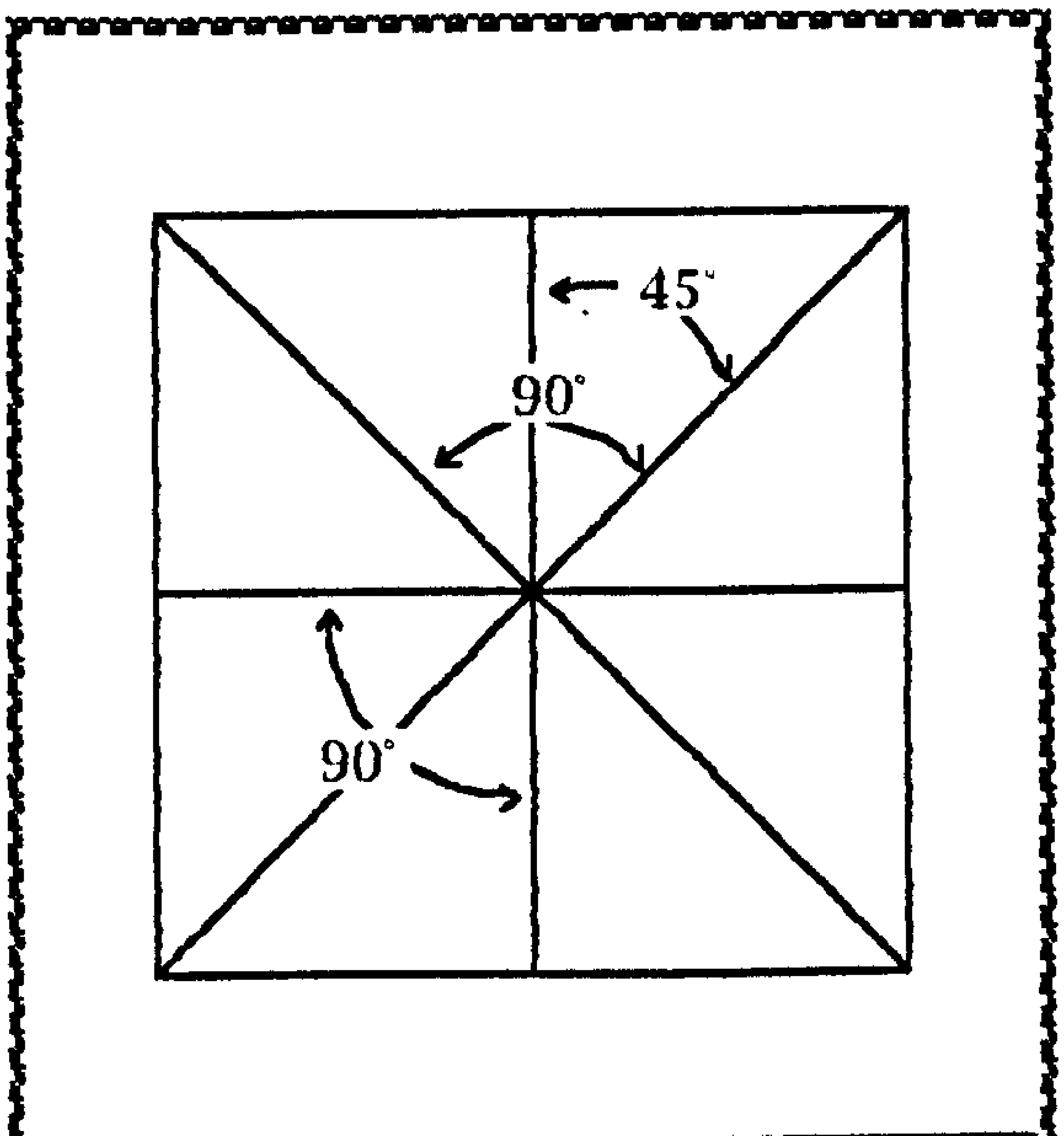


Figure APX. X-5. Exact angles between dimensions and cubic diameters

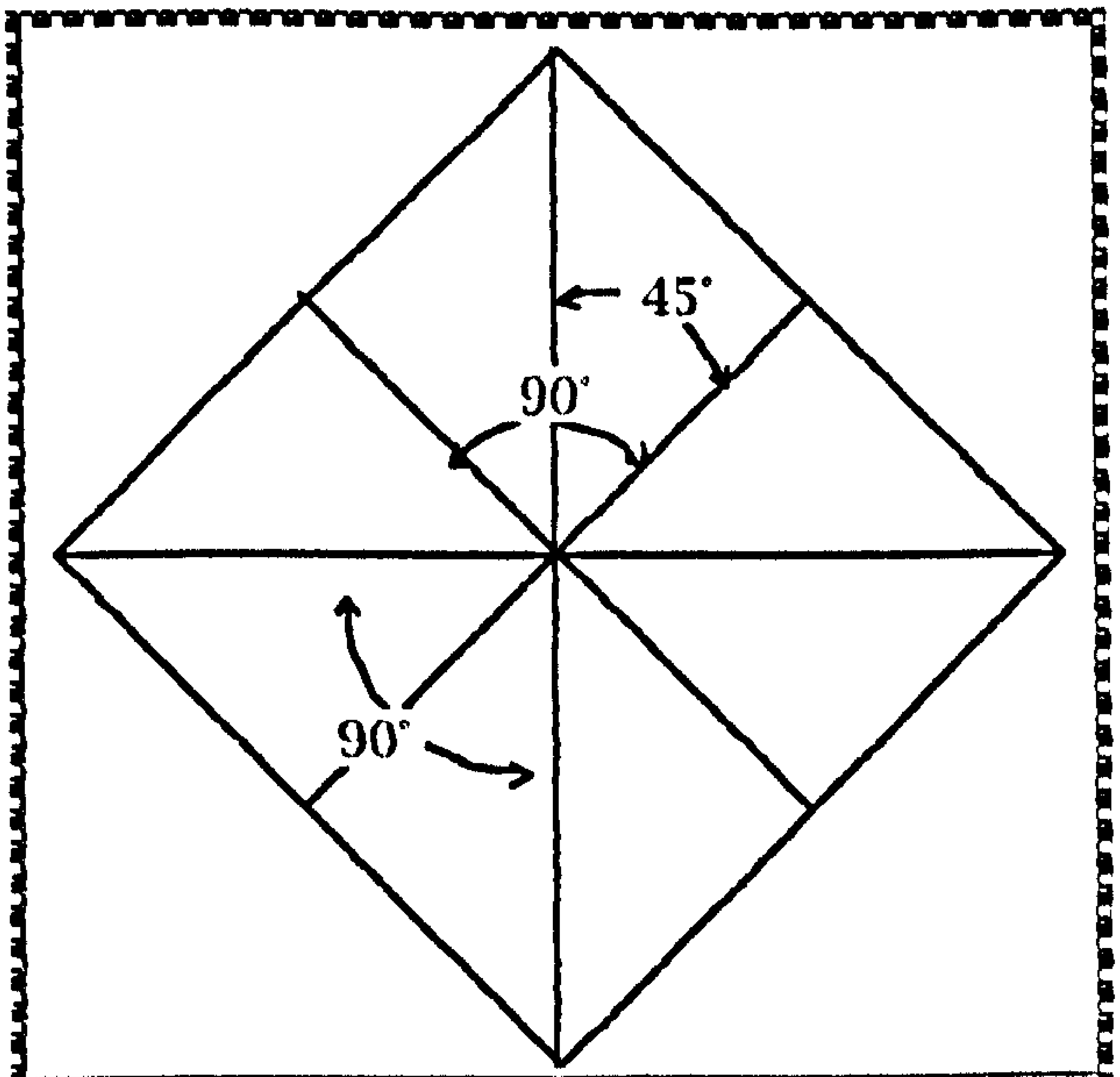


Figure APX. X-6. Exact angles between dimensions and octahedral diameters

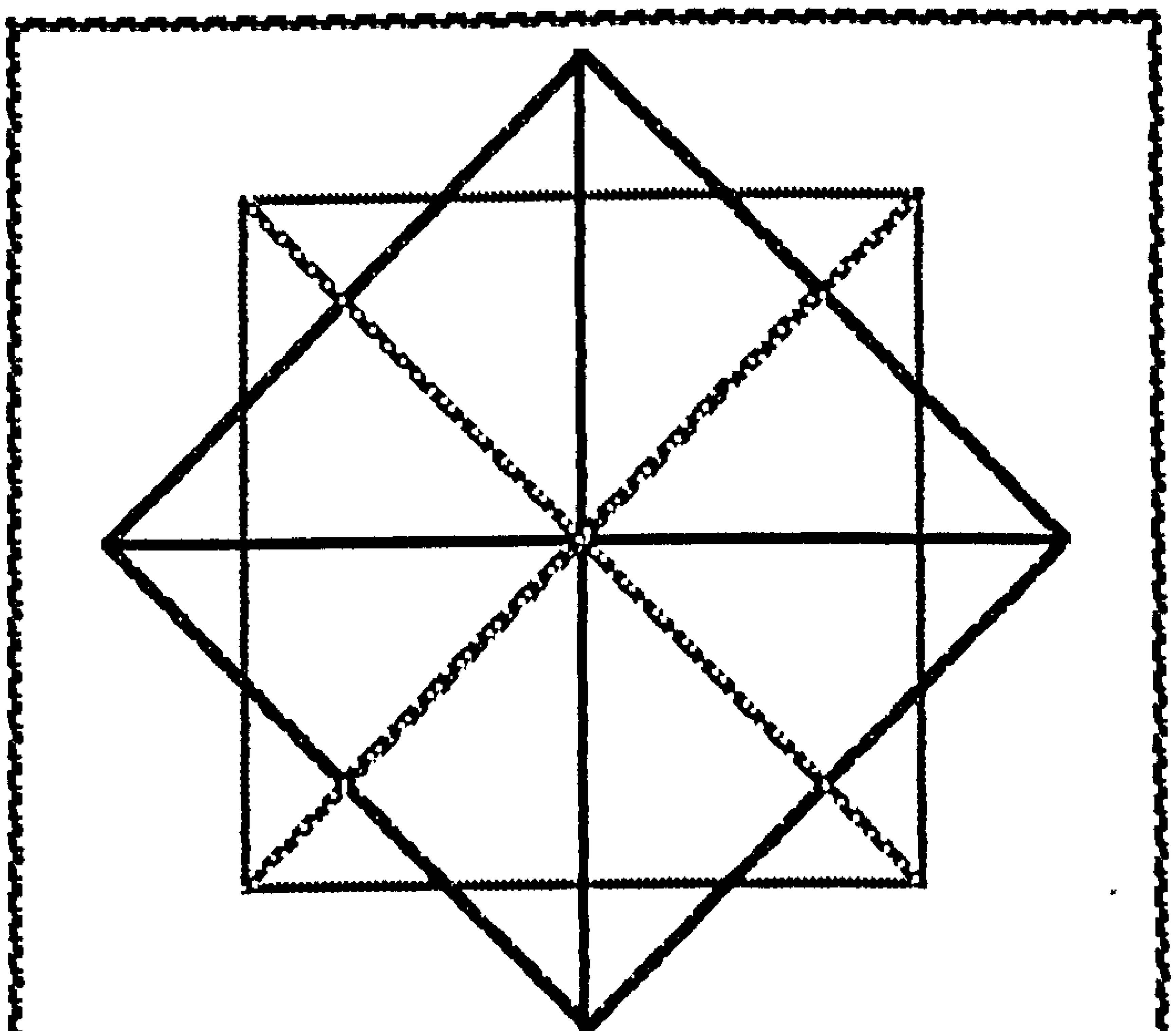


Figure APX. X-7. Interpenetrating cubic and octahedral planes

The angles between the diameters and dimensions in a cubic or octahedral Cartesian planes is exactly 45° and the angle between two dimensions, or two diameters will be exactly 90° (Fig. APX. X-5; Fig. APX. X-6). If the cubic and octahedral Cartesian planes are interpenetrated their diameters and dimensions will exactly align. This reveals how octahedral and cubic diameters are on the same angle relative to the dimensions (Fig. APX. X-7).

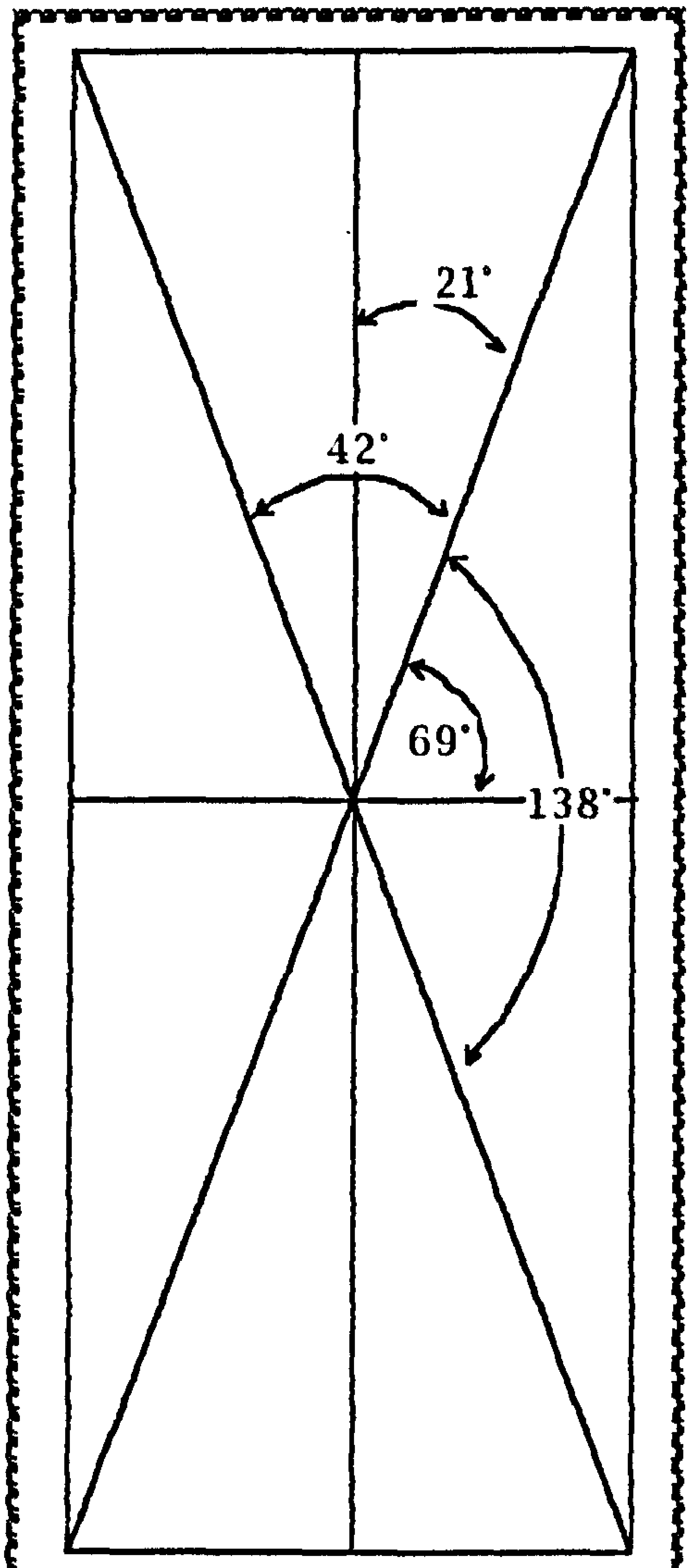


Figure APX. X-8. Approximate angles between dimensions and dodecahedral diameters.

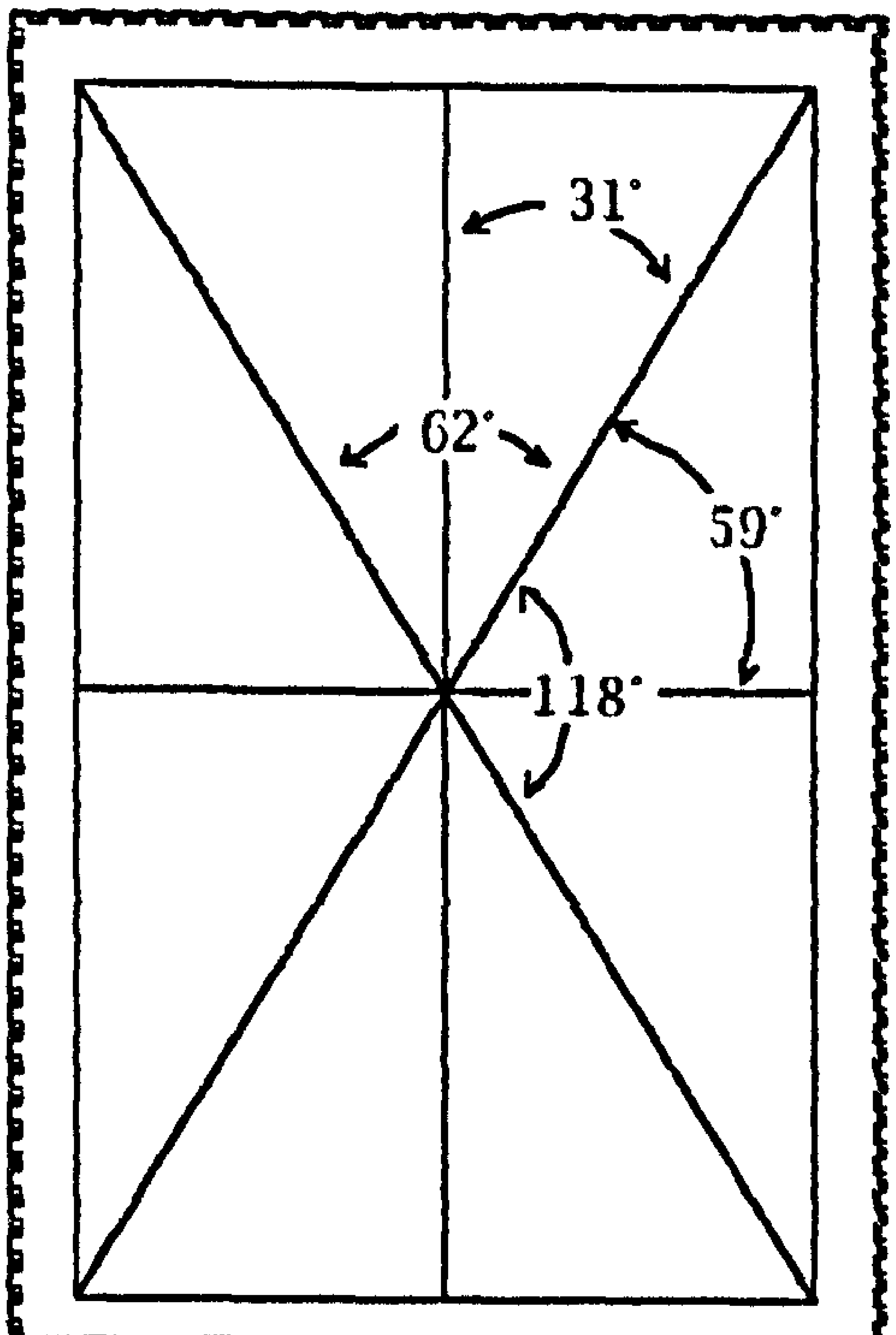


Figure APX. X-9. Approximate angles between dimensions and icosahedral diameters.

The angles between dimensions and icosahedral or dodecahedral diameters have been simply approximately measured with a protractor as represented in figure APX. X-8 and figure APX. X-9.

APPENDIX XI

RANGE OF ARTICULATION AT SINGLE JOINTS

A basic anatomical constraint is the range of movement at single-joints, or of the end of multi-joint skeletal linkages. Laban (1966, pp. 106-107) called these the "'zones' of the limbs" in which "the body and its limbs can be moved only in certain restricted areas of the kinesphere" and their "super zones" through which "every point of the kinesphere can be reached with any one limb". These have also been designated as the "joint range" versus the "cumulative range of the end member" in ergonomic research (Dempster, 1955, pp. 568-570; see IIB.42).

Laban (1966) explores the articulation ranges of individual joints and compares these with the hypothesized icosahedral-shape of the kinesphere. He identifies his joint-range data as coming from "Anatomists" who measured "a large number of people in 'normal' living conditions" and "measurements taken from lifeless human bodies" (p. 106; but the source of this data is not cited). Within ergonomic studies, Pheasant (1986, p. 145) points out that "There are surprisingly little joint range data available", and in their kinesiology text Rasch and Burke (1978, p. 32) add that measures of ranges of motion "are remarkable for their lack of agreement", probably because of considerable differences between subjects. However, some measurements are available about ranges of single joints and these can be used to reevaluate Laban's conclusions (for details about sizes of angles between dimensions and diameters in different networks; see Appendix X).

Laban (1966, pp. 106-107) reports that the "Flexion and extension angle of the head: (atlanto-occipital joint) [is] 45°". This is compared with the "Angle between dimensionals and diameters". This 45° angle between dimensions and diameters is only true within a cuboctahedral network, whereas in an icosahedral network (which Laban is explicitly discussing here) the angle between a dimension and a diameter is approximately 31° or 59° (depending on which dimension and which diameter).

It is unclear why the flexion+extension range of the atlanto-occipital joint is compared to the angle between dimensionals and diameters since this head movement actually spans an angle between two diameters (back-high to fore-high). The dimensional direction occurs when the head is oriented vertically upward. The range of neck articulation in the medial plane (which includes articulations in cervical vertebrae as well as the atlanto-occipital joint) have been measured at a mean average

(100 subjects) of 67° flexion (forward from vertical) and 77° extension (backward from vertical), yielding a total range of 144° (Damon et al., 1966, p. 193; Nordin and Frankel, 1989, p. 216). This angle does not appear to correspond to the smaller 118° angle between the icosahedral diameters fore-high to back-high.

Laban (1966, pp. 106-107) reports that "Generally we turn the head to either side at an angle of approximately 30°; turning further, as when looking over one's shoulder, requires the participation of an increased area of the body." Thus, the total "Rotating angle for the head: (at atlanto=axial joint) [is] 60°" Also, the "Turning angle of the vertebral column [is] 60°" and the "Tilting angle of the pelvic girdle [is] 60°". This 60° angle is compared to the "Angle between the neighbouring surface-lines [ie. two icosahedral edges within the same triangular surface] and also triangles formed by [icosahedral] transversals".

Here again the movement examples do not always correspond to the chosen angle in the icosahedral network. Head rotation and spinal rotation spans the angle between two diameters (fore-right/fore-left) or (at a larger range) between two dimensions (right/left). "Tilting angle of the pelvic girdle" (lateral tilting?) spans the angle between the deep-right and deep-left diameters.

This 60° angle in an icosahedral network does not correspond to an angle from one limb position to another with the angle's vertex at the centre of the joint (as measured for angles of joint motion). The angle which Laban describes is an angle with its vertex on the periphery of an icosahedron and so would refer to an angle between two lines of motion, not between two limb orientations. This has no relation to joint ranges in which the angle's vertex is conceived as the centre of the kinesphere.

The angular range of neck rotation (mean for 100 subjects, and probably including cervical rotation in addition to atlanto-axial rotation) has been measured at 74° towards the right or left from forward (Damon et al., 1966, p. 193). This total neck rotation range of 148° does not correspond to the much smaller 118° between icosahedral fore-right and fore-left diameters. Nordin and Frankel (1989, p. 216) report total neck rotation at 180° which is identical with the 180° between the right and left dimensional directions.

Laban (1966, pp. 106-107) reports that the "Angle between flexion and extension of the vertebral column", and the "Turning angle of the hips [is] 72°." This is compared to the "Angle at the base of a triangle formed by transversals and a [peripheral] surface-line". As in the proceeding example, the angle described by Laban has its vertex on the periphery of the icosahedron and so does not correspond to a joint range angle in which the vertex would be located at a joint conceived at the centre of the kinesphere.

The total flexion/extension angle of the thoracic and lumbar spine is listed as 80° (Ellison, 1993, p. 67). By "Turning angle of the hips" it is assumed that Laban is referring to rotation of the femur in the hip joint. With the hip joint in the neutral position (neither flexed or extended) the range of hip rotation has been measured at a total of 73° (mean for 39 college males of various builds) (Damon et al., 1966, p. 192). These measurements are close to Laban's and come close to corresponding to the 90° between cuboctahedral fore-right and fore-left diameters, but are considerably less than the 118° between icosahedral fore-right and fore-left diameters.

Laban (1966, pp. 106-107) reports that the "Abduction of shoulder joint or lifting angle of the arm sideways (without movement of the scapula) [is] 90°". This is compared to the "Angle between two dimensions". This comparison between body movement and the angle within the kinespheric network is the best of all of Laban's examples. When an arm is oriented downwards it is aligned with the vertical dimension and when it is abducted upwards and to the side it can move into alignment with the lateral dimension (although this is relative to an octahedral-shaped kinesphere rather than the icosahedron which Laban has been discussing).

Separating articulation within the glenohumeral joint (shoulder) from the motion of the scapula is difficult since in studies of kinesiology (Rasch and Burke, 1978) it is found that during "natural movements" scapula motion will always occur together with shoulder articulations (p. 169). Abduction of the arm will occur at most for 30° before the scapula begins to rotate upwards 1° for every 2° of shoulder articulation (p. 170). This is a good example of Laban's (1966, pp. 106-107) law of "determinable contributory movements" for multi-joint articulations. It is curious why Laban discusses this unnatural movement of isolated glenohumeral articulation when one of his principal reasons for studying movement is because of its harmony:

> The beauty and simplicity of this harmony has always touched me profoundly. It is this which has led me to study movement and to explore the significance of this means of human expression.
> (Laban, 1951, p. 11)

Measures of shoulder articulation typically include the naturally accompanying motion of the scapula and so cannot be compared with Laban's observation. However, the measurement of 30° of humerus abduction during which the scapula "may" remain stationary (Rasch and Burke, 1978, pp. 169-170) is virtually identical to the 31° angle between vertically downwards and the icosahedral side-deep diameter.

Laban (1966, pp. 106-107) reports that the "Flexion and extension of [the] shoulder joint or lifting angle of the stretched arm forward and backward (without rotating the scapula) [is] 108°". This is compared to the "Angle between two non-neighbouring [peripheral] surface-lines [ie. icosahedral edges which are not part of the same icosahedral surface]".

As discussed above in regards to humerus abduction, in "natural movements" flexion and extension of the shoulder joint always occurs together with scapula motion. Therefore, measures of shoulder motion typically include the naturally accompanying motion of the scapula and so cannot be compared with Laban's observation. However, shoulder articulation which "may" flex up to 60° without scapula motion (Rasch and Burke, 1978, pp. 169-170) is virtually identical to the 59° between the downwards dimension and the icosahedral deep-forward diameter.

Shoulder articulation (with scapula rotation) has been measured as 188° flexion and 61° extension from the vertically downwards position (mean for 39 college-age males of various builds) (Damon et al., 1966, p. 191; Ellison, 1993, p. 70; Nordin and Frankel, 1989, pp. 225-228; Pheasant, 1986, p. 147). This 188° of flexion corresponds closely to the 180° between vertically downwards and vertically upwards dimensions in an octahedral-shaped kinesphere. The 61° of extension is virtually identical to the 59° between the downward dimension and the icosahedral back-deep diameter.

Other comparisons were not mentioned by Laban but can also be made between joint ranges and angles between dimensions and diameters. Hip flexion and knee flexion have been measured (mean for 39 college-age males of various builds) (Damon et al., 1966, p. 192; Pheasant, 1986, p. 147). Hip flexion (with knee allowed to flex) averaged 113° from dimensionally downward (or 120°; Ellison, 1993, p. 68). This is close to the 121° between the downwards dimension and the icosahedral up-forward diameter. Knee flexion (with the thigh oriented vertically downwards while standing) also averaged 113° (or 135°; Ellison, 1993, p. 68) which is close to the 121°

between the downwards dimension and the icosahedral up-backward diameter.

Shoulder articulation in the horizontal plane has been measured as 48° for horizontal flexion and 134° for horizontal extension from the dimensionally forward position (mean for 39 college-age males of various builds) (Damon et al., 1966, p. 191; Ellison, 1993, p. 70; Nordin and Frankel, 1989, p. 228; Pheasant, 1986, p. 147).* These angles are virtually identical to the 45° between the forward dimension and the cuboctahedral fore-left diameter and the 135° between the forward dimension and the cuboctahedral back-right diameter.

Lateral flexion of the neck (tilting the head side/side) has been measured as 41° to either side from the upwards dimension (mean for 10 males) (Damon et al., 1966, p. 193) or a total of 90° lateral flexion (Nordin and Frankel, 1989, p. 216). This is identical to the 45° between the upwards dimension and cuboctahedral right-upwards or left-upwards diameters. Lateral flexion of the thoracic and lumbar spine is listed as 35° (Ellison, 1993, p. 67) which is virtually identical to the 31° angle between dimensionally upwards and the icosahedral up-right (or up-left) diameter.

Conclusions.

The measurements of ranges of single-joint articulations does not provide evidence for particular shapes of the Cartesian planes. As indicated above, some joint articulation ranges correspond to cuboctahedral diameters, others correspond to icosahedral diameters, while others correspond to dimensions (octahedral).

Furthermore, a joint range may correspond to particular angles in the kinesphere depending on how the joint is oriented. For example, the range of elbow flexion has been measured as 142° from an extended elbow to a fully flexed elbow (mean for 39 college-age males of various builds) (Damon et al., 1966, p. 191). If the upper-arm is oriented in the forward dimension then this 142° could be compared to the angle between the forward dimension and either the icosahedral or the cuboctahedral up-backwards diameter (149° or 135° respectively). If the upper-arm is oriented in the rightward dimension then this 142° could be be compared to the angle between the rightward dimension and either the icosahedral or cuboctahedral left-forwards diameter (also 149° or 135° respectively). However, if the upper-arm is

* The authors cited refer to this as "adduction" and "abduction" but the drawings provided by Damon and Colleagues (1966, p. 194) confirm that the motion measured is in the horizontal rather than the frontal plane. Following Rasch and Burke (1978, p. 160) this motion is referred to here as "horizontal flexion" and "horizontal extension".

oriented in the downwards dimension, then the 142° angle could be compared to the 135° angle between the downward dimension and the cuboctahedral up-forward diameter but this would not correspond to the icosahedral up-forward diameter which is a much smaller 121°. Thus, the range of elbow articulation cannot be said to definitely correspond with either icosahedral or cuboctahedral diameters.

Therefore, measurements of articulation ranges of individual joints do not provide a coherent picture of the shape of the kinesphere. Deciphering the shape of the kinesphere should not be determined from individual joint ranges anyway. Conclusions about the space used by the whole body from data of individual joints would not be ecologically valid since in the vast majority of cases the body does not move at single isolated joints. Rather, organic movement consists of coordination among collections of joints such as "coordinated structures" in which kinematic chains of body-segments function as a group rather than individually (see IIIB.60). If the kinesphere has particular shapes they should be evident in observations of organic movements involving integrated, coordinated collections of joints and body-segments rather than individual joint articulations.

There is also no reason to believe that individual joints are articulated to their full range during organic movement. Indeed, one may expect that when possible the full range of joint movement would not be used because of the ecological advantage of maintaining some margin for error (for when you really need it). Other considerations are more likely to govern the shape of the kinesphere. For example, the directions and range of motion might be governed by the need to maintain equilibrium, the creation of a meaningful communicative expression, the desired quality of the movement (eg. delicacy, forcefulness), or by the exterior spatial layout of a particular task (eg. locations of shelves around a workspace).

An underlying factor within all of the examples given above which may govern the shape of the kinesphere is the desirability for the movement to achieve its goal in the most efficient way possible. This is "another important principle of body mechanics: the individual tends to function in the way that affords the greatest conservation of energy" (Rasch and Burke, 1978, p. 98). Laban (1966, p. 45) refers to this as "economy of effort" according to which "It is natural for all living organisms to use the simplest and easiest paths in space". The ecological need for economy may be the greatest consideration which governs the shape of the kinesphere.

APPENDIX XII

DEFLECTED BALLET

The process of organic deflections away from dimensional and diagonal prototypes can be used to determine the inclinational directions which occur in dance technique. This can be begun by examining the actual inclinations which occur in well known standardised dance exercises. Ballet technique lends itself to this because the movements have been well systematised and their dimensional conception is usually explicit.

Much of ballet training consists of attempts to eliminate the deflections which arise naturally from the body's anatomical constraints. The goal of ballet training is to embody the idealised image of pure dimensional and pure diagonal lines. These can be approached by increasing flexibility at the joints. However, the best that can be hoped for is to minimise the the inclinational directions which naturally arise from the body.

As an alternative, in the choreutic conception, or what Laban (1926, p. 64) called the "new dance", the explicit production of inclinations is encouraged. Mentally imagining inclinational directions is more difficult than imagining dimensional directions. This difficulty also evident in Labanotation direction symbols in which inclinations are typically notated as the line from one directional point to another. To simplify the mental representation of inclinations they can be conceived according to their dimensional and diagonal components. This conception of inclinational directions is utilised in Laban's earlier (1926) notation system, referred to here as "vector-symbols".

Ballet technique presents a wealth of dimensionally conceived paths and poses. The alignment of these dimensionally conceived directions with the octahedral-shaped kinesphere has been identified by some researchers (Lepczyk 1987), however the actual body movement rarely aligns with the pure dimensions. The principle of deflection can be applied to these movements to decipher the organic inclinations which actually occur. These inclinations can be represented according to their dimensional and diagonal components with vector symbols.

What is found is that a particular sequence of dimensional directions might be deflected in several different ways along different diagonals. Thus, there is no one-to-one correspondence between a dimensional prototype and the actual deflected inclination. The actual deflection will depend on the style, intention, and habits of the mover. Certain inclinations could also be chosen by the mover in which to strive, thus encouraging a particular result.

By determining the inclinational directions which occur during systematised ballet movements a dance technique can be derived which is an inclinational version of ballet. This can be a good starting place for the propagation of inclinational conceptions in dance. Several common ballet movements and positions will be considered here as examples.

<u>Second Position of the Gesturing Leg</u>.

Possibly the most well known deflection in ballet occurs when the leg attempts to move towards a lateral dimension. In the ideal conception the second position of a gesturing leg is directly to the side. The location of this leg is related to the degree to which the leg can rotate at the hip-joint, that is the degree of "turn out". The ideal in ballet is that the hip can rotate outward far enough so that the anterior surface of the leg is faces laterally. Thus when the hip flexes the leg can move towards the lateral dimension. However, most bodies do not have this much range of hip rotation. Thus the conceived position of the right-leg to the rightward dimension actually occurs towards a right-forward diametral direction.

<u>Arm Positions Fifth High, Fifth Low, and Second</u>.

Another deflection from the dimensional prototype occurs in arm positions downward, to the side, and upward. These dimensionally conceived arm positions are all intentionally deflected slightly towards the diametral directions down-forward, side-forward, and up-forward. This deflection occurs because of the limited range of the shoulder-joint. In order for the arms to orient purely within a vertical or lateral dimension (or anywhere in the midfrontal plane) the scapula must retract backwards towards the spine. This scapula retraction begins to distort the vertical posture which (in ballet) is more important than the exact positions of the arms, and so it is discouraged. When the arms are positioned slightly forward of the midfrontal plane then the scapula can remain flat on the back and the vertical posture maintained.

<u>*Passé*</u>

A fundamental movement is ballet is known as "*passé*" and usually refers to when the foot of the gesturing leg "passes" the knee of the standing leg while it is moving from one position to another (Grant, 1982, p. 81). A *passé* can be described as a series of three poses. For example, in the first pose the right-foot might begin in fifth-position front with the weight evenly distributed on both feet. In the second pose the right-foot is placed to the side of the left-knee with the body's weight entirely on the left-leg. In the third pose the right-foot is placed on the floor in fifth-position back with the weight on both feet. In this example the three poses can be conceived as dimensional locations for the right-foot (Fig. APX. XII-1).

The deflected directions are fairly simple in this case. The *passé* occurs in two single-phase paths. The direction of the paths can be taken from the path of the centre of gravity* of the right-leg. In the first path the centre of gravity of the entire body and of the right-leg shifts backwards as the weight is transferred onto the left-leg. The leg also raises upwards, and (because of "turn-out" in ballet) the centre of gravity of the right-leg travels rightward. This identifies the first path of the centre of gravity of the right-leg as moving along the up-right-backward diagonal direction.

During the second path the centre of gravity of the right-leg moves downward, leftward (toward the medial plane), and backward as the leg moves to fifth-position back and the weight shifts onto both legs. Thus the second path of the centre of gravity of the right-leg moves along the down-left-backward diagonal direction.

The dimensional content of the inclinations is suggested by the conceptual dimensional prototype in which the intention of both paths is in the vertical dimension. The sagittal motion is small, created by the shift of the whole body onto the back leg. The lateral motion is also small. The largest dimensional component of the motion is vertical. This identifies both inclinations as steep deflections (Fig. APX. XII-1; Deflection A).

Other deflections might also occur during a *passé*. Because of the limits on outward rotation at the hip, and if the weight is already entirely on the left-leg (thus no weight shift is required) then the first path of the centre of gravity of the right-leg may follow the up-right-forward diagonal (Fig. APX. XII-1; Deflection B). This may be

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* The centre of gravity is a "mathematical construct having no physical reality" but which is used since it "greatly simplifies computation and understanding"; it is the location where all of the object's mass could be concentrated and the total gravitational force exerted on the object would be the same (Rasch and Burke, 1978, p. 93), or "'that point in a body about which all the parts exactly balance each other'" (Wells and Luttgens, 1976, p. 20). The location of the centre of gravity will shift depending on the configuration of the body-parts and it is not always located within the physical body itself (eg. in a curled limb the centre of gravity is located somewhere near the centre of the curve. The centre of gravity can be abbreviated as "cg" (Collins, 1986).

especially pronounced if the calf begins to gesture to the side rather than keeping its purely vertical intent. In this case it is deformed into a similar movement known as "*attitude á la seconde*" in which the knee is only slightly bent ("*attitude*") and the leg is gesturing toward the side (second position). For example, when the right leg is lifted from fifth-position front into *attitude á la seconde*, because of the limited range of hip rotation its pathway may follow the up-right-forward diagonal. However, with greater range of hip rotation, and with larger shifts of weight onto the back foot (eg. if begun in fourth-position), then the motion may follow the up-right-backward diagonal.

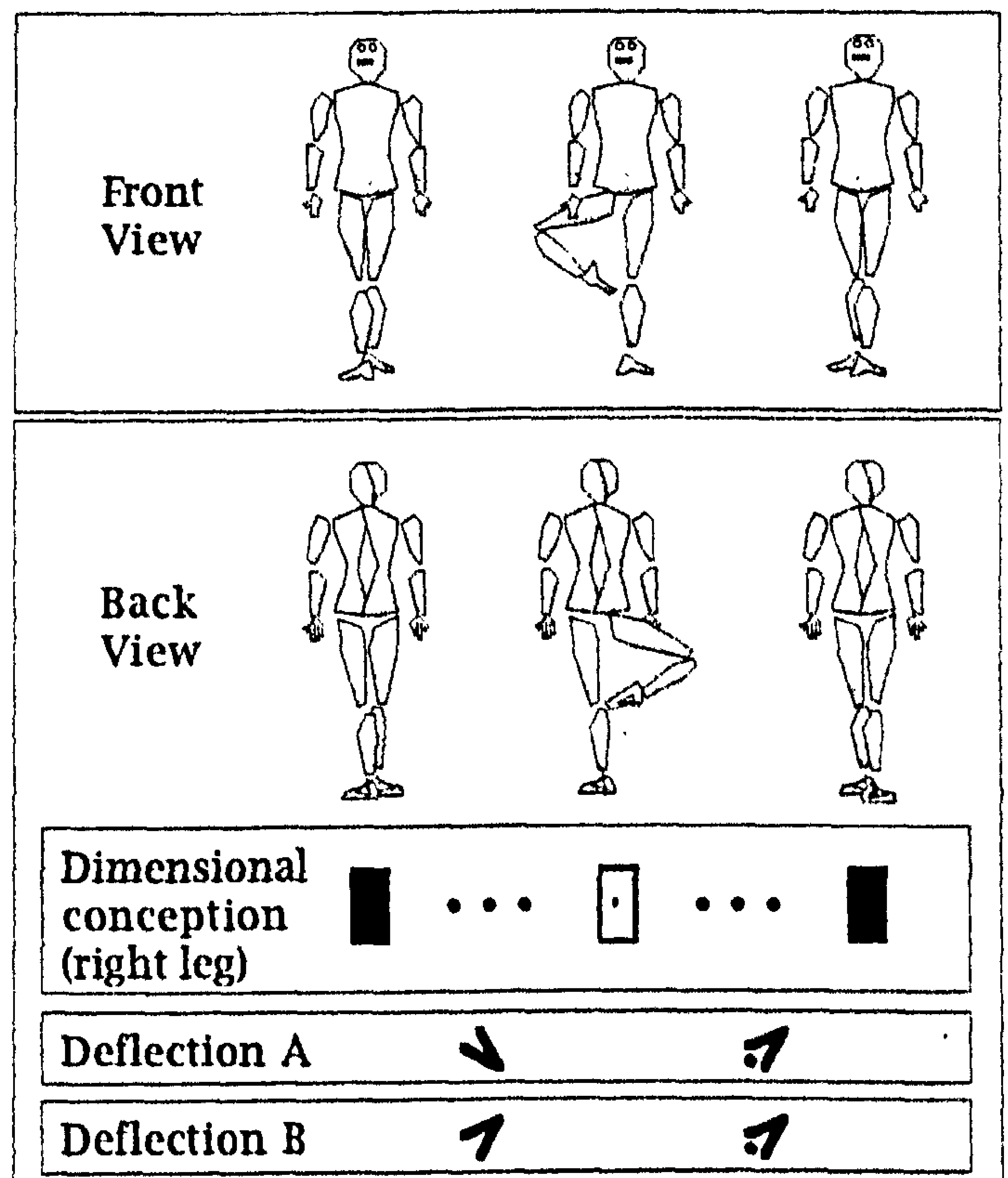


Figure APX. XII-1. *Passé.*

In both the *passé* and the *attitude á la second* (and other moves eg. *développé á la seconde, grand battement á la seconde*) maintaining an intention towards the up-right--backward diagonal (for the right-leg) encourages the continuous production of outward hip rotation. Conceiving of *passé* (and other movements) as the inclinational direction of motion, rather than a dimensional position may create a quite different kinesthetic sensation for the mover. A positional conception encourages the limb to be held in a static position. A directional vector-like movement conception encourages the limb to strive along this direction of motion, even as the limb stops moving at the extremity of its range. For example, in a *passé* the leg would continue to strive up-back-rightward even when the hip has reached its maximum flexion and outward rotation. This has an effect maintaining muscular activity and continuing to expand the range of motion rather than remaining fixed in a held position.

Développé á la Quatriéme Devant.

Another fundamental and common movement in ballet is referred to in the French as "*développé á la quatriéme devant*", that is, a developing of the leg into the fourth-position forward in the air. This movement can be described as a series of four poses. For example, the first pose may consist of the weight on both feet standing in the first-position. The second pose consists of the right-foot pointing at the left knee with the weight entirely on the left-foot. The third pose consists of the right-leg gesturing towards the dimensional forward direction. The final pose is the same as the first pose; first-position with weight on both feet. This sequence of four poses can be conceived as dimensional directions following the positions of the right-foot (Fig. APX. XII-2).

The deflected directions can be taken from the path of the centre of gravity of the right-leg. This movement occurs in three single-phase paths.

The first path follows a steep deflection of the diagonal up-right-backward, almost identical as described for the *passé* movement (see above).

For the second path the centre of gravity of the right-leg begins to the right of the medial plane and so during the motion towards the dimensional forward direction the leg also moves leftward, towards the medial plane. The upwards or downwards component will depend on the range of motion and strength of the particular subject. For the normal person the leg will drop slightly while moving forward. Thus this second path of the centre of gravity of the right-leg might occur as a suspended deflection of the diagonal down-left-forwards.

The final path takes the centre of gravity of the right-leg back and downwards toward the floor. In addition a small component of rightwards motion may occur as the weight of the body shifts rightwards onto both feet. This produces the diagonal direction down-back-rightwards. The principal dimensional component will probably be sagittally backwards (depending on the performance) (Fig. APX. XII-2; Deflection A).

Other deflections are also possible. If the right-foot begins from the back then the first inclination will be along the up-right-forward diagonal (rather than backward) (Fig. APX. XII-2; Deflection B).

If the mover has a great deal of hip flexibility and strength, then the second inclination may be along the up-left-forward diagonal (rather than downward). This conception of an inclinational motion will encourage the mover to continually increase the strength and range of motion. In this case the primary dimensional component of the final inclination would be vertical. This might be performed with the first path along the up-right-backward diagonal (Fig. APX. XII-2; Deflection C) or along the up-right-forward diagonal (Fig. APX. XII-2; Deflection D).

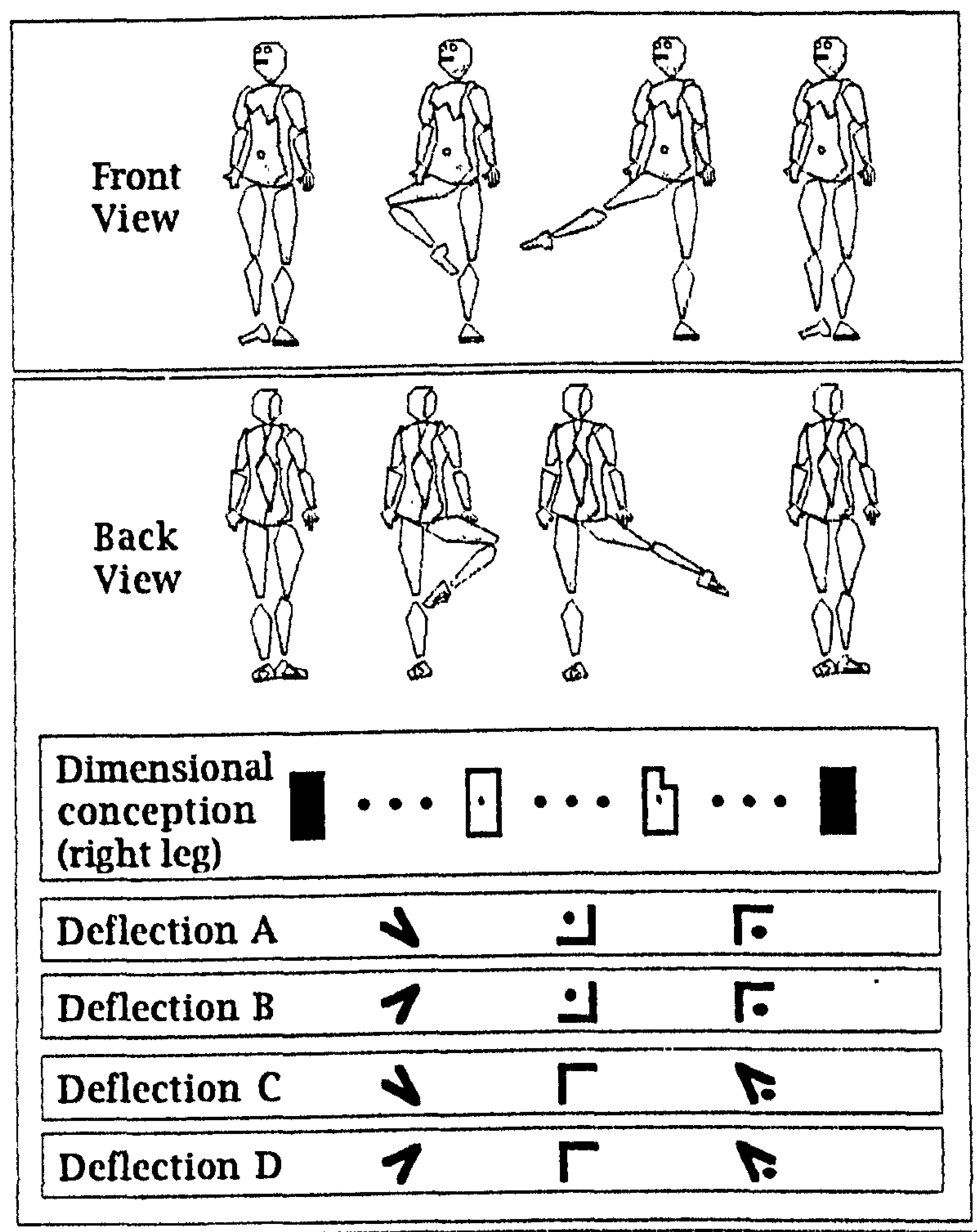


Figure APX. XII-2. *Développé á la quartiéme devant.*

It may be possible to closely confine this motion to a paramedial plane. If the leg is brought into fifth-position to conclude the movement the third path may closely approximate a purely planar arc moving back-downwards (lateral motion minimized). Also, if the entire motion is performed in "parallel" position (anterior surface of the legs oriented forward), and the weight remains on the same leg throughout (no lateral weight-shifts), then the three pathways of the centre of gravity of the leg. may remain closely confined to a paramedial plane. However, this is not a natural condition since during knee articulation the femur and the tibia do not remain in the same plane (Gray

1977, p. 279; see IVA.70) and so during the *développé* either the upper-leg or the lower-leg will necessarily deviate away from the paramedial plane.

<u>*Renversé en Dehors*.</u>

A more complex movement is referred to in the French as "*Renversé en dehors*". In the discussion here only the first part of the *renversé* will be considered which consists of a large sweep of the leg ("*grand rond de jambe*") from front to back (Grant 1982, pp. 96-97).

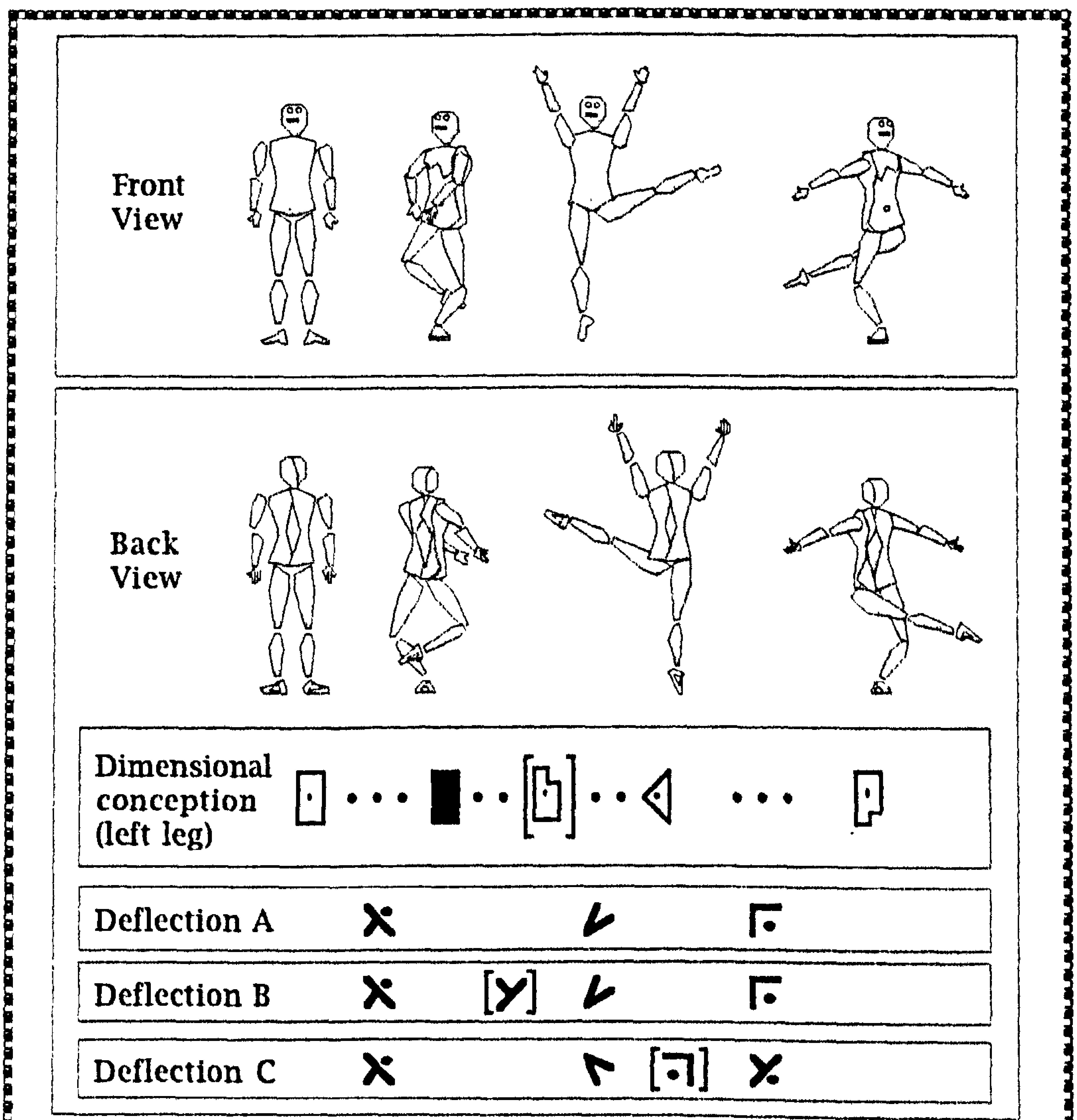


Figure APX. XII-3. *Renversé* (first half).

The first part of the *renversé* can be defined as a series of four poses. For example, the first pose might consist of the weight on both feet in fifth-position with the left-foot forward (other positions could also be used as preparation). The second pose is after a step forward with the left-foot, right-foot lifted slightly behind. In the third pose the left-leg is extended to the side with the weight on the right-foot. In the final pose the left-leg is gesturing behind the body with the weight still on the right-foot. These four poses can be conceived as dimensional directions for the left-leg (Fig. APX. XII-3).

The deflected directions can be taken from the path of the centre of gravity of the left-leg.. This movement occurs in three single-phase paths.

The first path consists primarily of the step forward while also bending the legs (centre of gravity moving downwards) and a slight turning to the side following the shift of weight rightwards during the step. Thus the pathway moves along the down-right-forwards diagonal. Past observations of this movement indicate that the lateral dimension is stressed in the preparation as a sort of "wind-up" for the uncoiling of the dynamic leg-swing to follow. Therefore it is notated as a flat deflected inclination here.

The second path consists primarily of the left-leg moving upwards and leftwards to the side while also shifting the weight backwards onto the right-foot. Thus the pathway occurs as a steep deflection of the up-left-backwards diagonal.

The third path consists of the left-leg reaching backwards while also moving downward and rightward (toward the median plane). Thus this path occurs as a suspended deflection of the down-right-backward diagonal (Fig. APX. XII-3; Deflection A).

A short intermediary path will probably occur between the first and second path. This intermediary path might move along a flat deflection of the up-left-forward diagonal just previous to the up-left-backward diagonal of the second path. This may occur when the left-leg is straightened just prior to the second path and so its centre of gravity is initially carried forward in a deflected horizontal planar arc (Fig. APX. XII-3; Deflection B). This arc could also move down-left-backward before the up-left-backward path (deflected frontal planar arc), but this is a great enough variation that the resultant movement would probably no longer be considered to be a *renversé*.

Another deflection might occur in which the second path of the centre of gravity of the left-leg moves up-left-forward (rather than backward) because of limited hip flexibility. This might be followed by a suspended deflection of the diagonal down-left-backwards as a short intermediary pathway in an attempt to maintain the leftward dimension before concluding with the down-right-backward diagonal (now as a flat deflection) (Fig. APX. XII-3; Deflection C). However, a vital part of the *renversé* is the shift of weight onto the back leg leading into the second pathway. This backwards motion, and the intention to move the leg towards the lateral dimension, encourages the second path to progress along a backwards leading diagonal, rather than forwards.

Conclusions: Deflected Ballet .

These examples indicate how dimensionally conceived ballet movements can be observed to actually deflect along inclinational directions. While it is possible to restrict the body movement so that it appears to remain entirely within pure dimensions or Cartesian planes, this is not what typically occurs. This is especially true for highly dynamic movement. Fine anatomical details also reveal that pure Cartesian planes of body motion do not normally occur (see IVA.70).

Inclinational deflections can be determined for all types of ballet movements. A conception of movement in terms of its inclination is an entirely different conception than is used in dance today and has the potential to create entirely different kinesthetic sensations in the performer.

The choreutic conception can be considered to be a counter-part to the ballet conception. Ballet is based on a conception of dimensions which are implicitly deflected towards nearby diagonals during actual body movement. In contrast to this, choreutics is based on a conception of diagonals which are explicitly deflected towards nearby dimensions during actual body movement. Laban (1926, p. 64) summarises that ballet is "oriented in dimensional stability" while the "new dance" is "oriented in diagonal lability" and so Laban used the choreutic diagonal scale as the principal exercise in his dance technique classes (Bodmer and Huxley, 1982, p. 18). A few examples of ballet movements deflecting into inclinations are given here. The further development of a choreutic diagonally-based para-ballet movement technique is possible with an understanding of organic deflections into inclinational directions. This is a direction for future research. (See IVA.60,.80.)

APPENDIX XIII

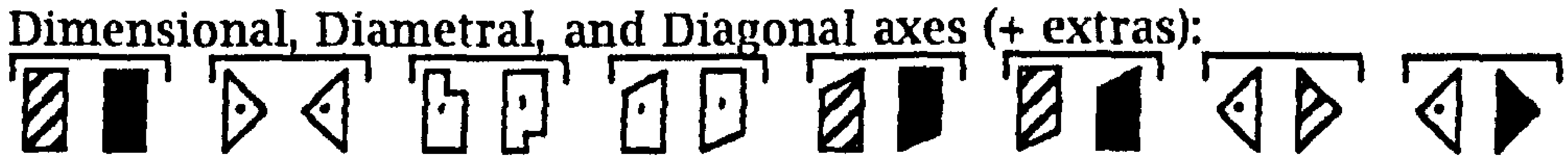
REFERENCE POINTS IN KINESTHETIC SPACE: STIMULI AND RAW DATA

APX. XIII.10 The 59 Stimulus Pairs

Distractor-pairs:

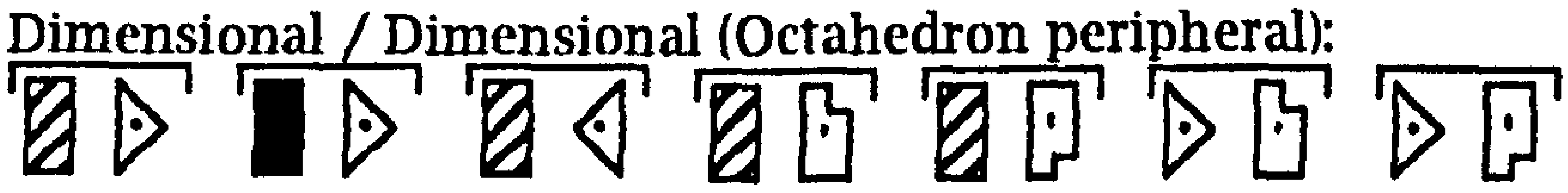
Dimensional and Diagonal radii (Cube and Octahedron central):

Dimensional, Diametral, and Diagonal axes (+ extras):

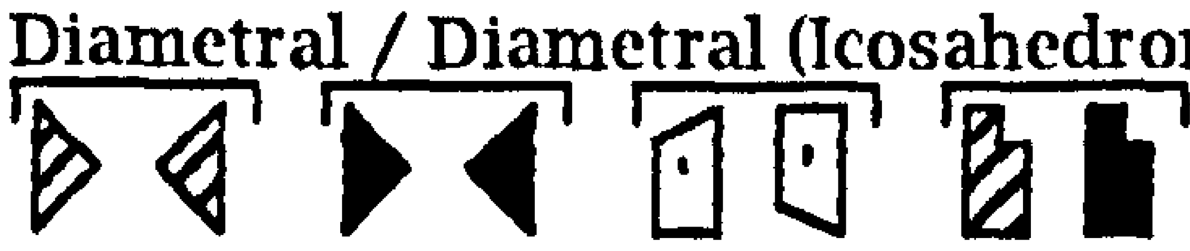


Same-type test-pairs:

Dimensional / Dimensional (Octahedron peripheral):

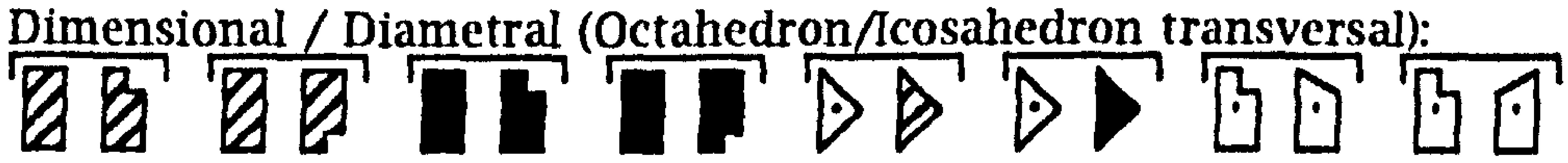


Diametral / Diametral (Icosahedron peripheral):

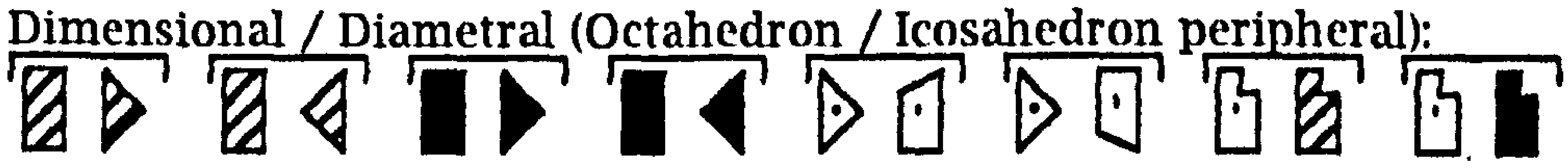


Different-type test-pairs:

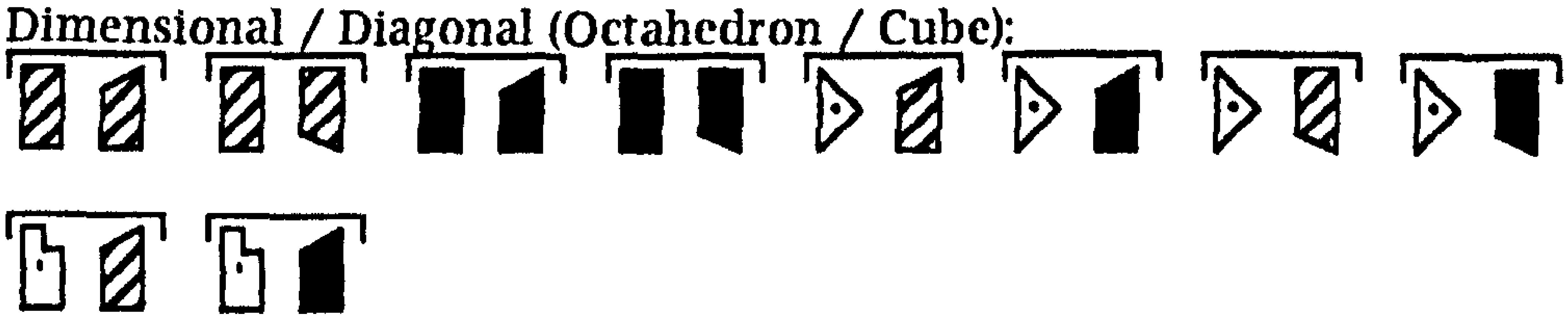
Dimensional / Diametral (Octahedron/Icosahedron transversal):



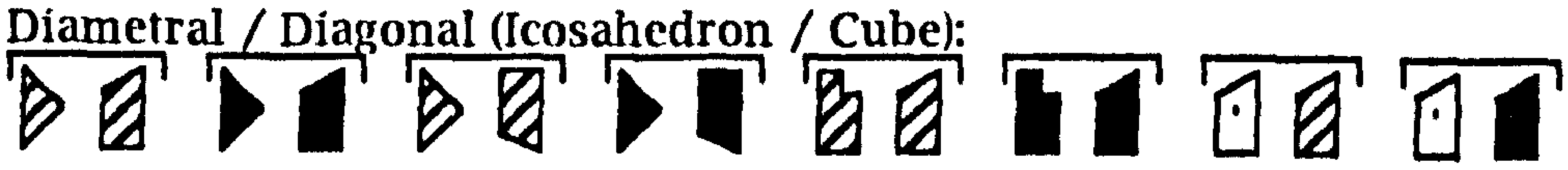
Dimensional / Diametral (Octahedron / Icosahedron peripheral):



Dimensional / Diagonal (Octahedron / Cube):



Diametral / Diagonal (Icosahedron / Cube):



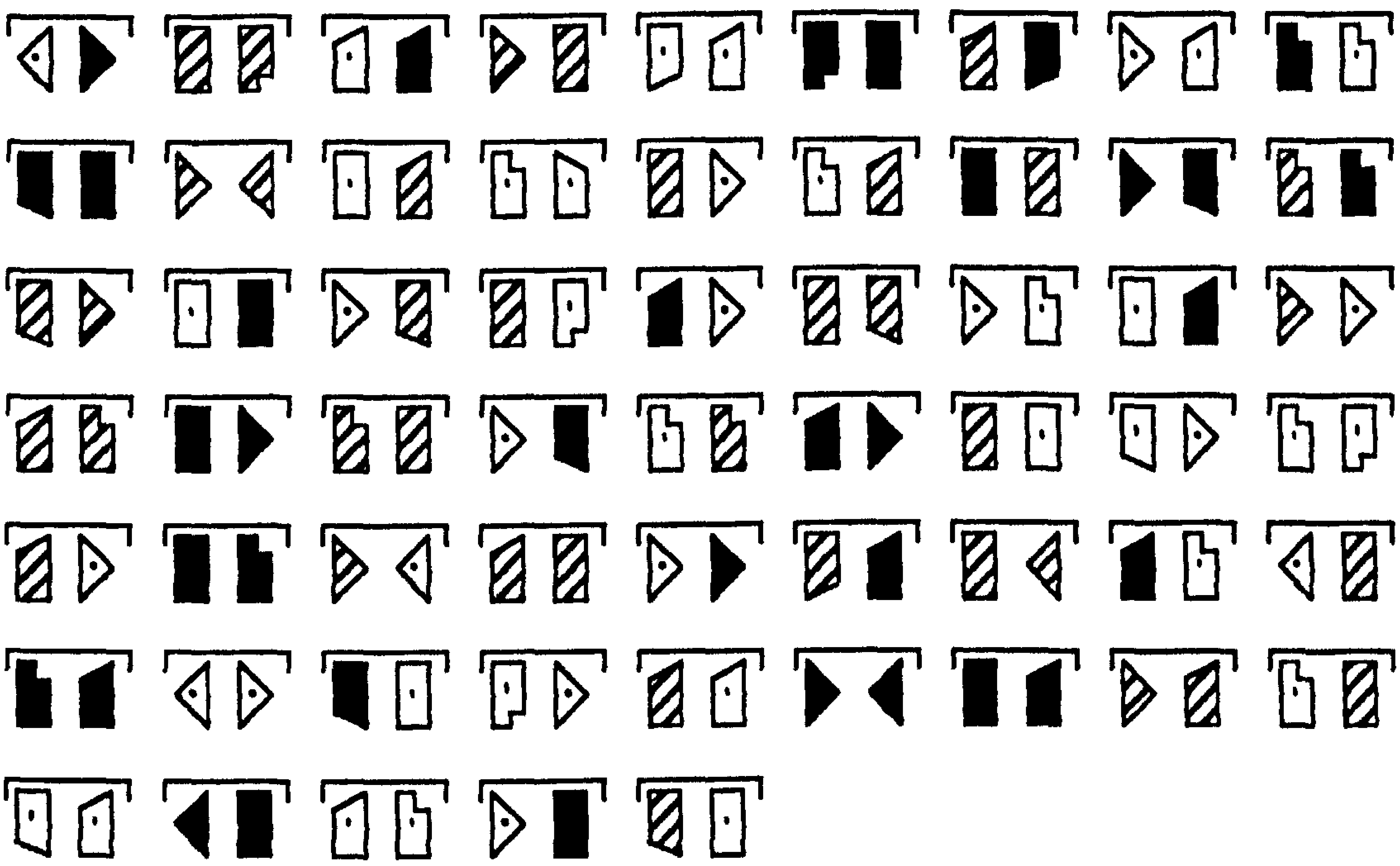
Warm-up Stimuli-pairs:

APX. XIII. 20 Example of Actual Order of Presentation

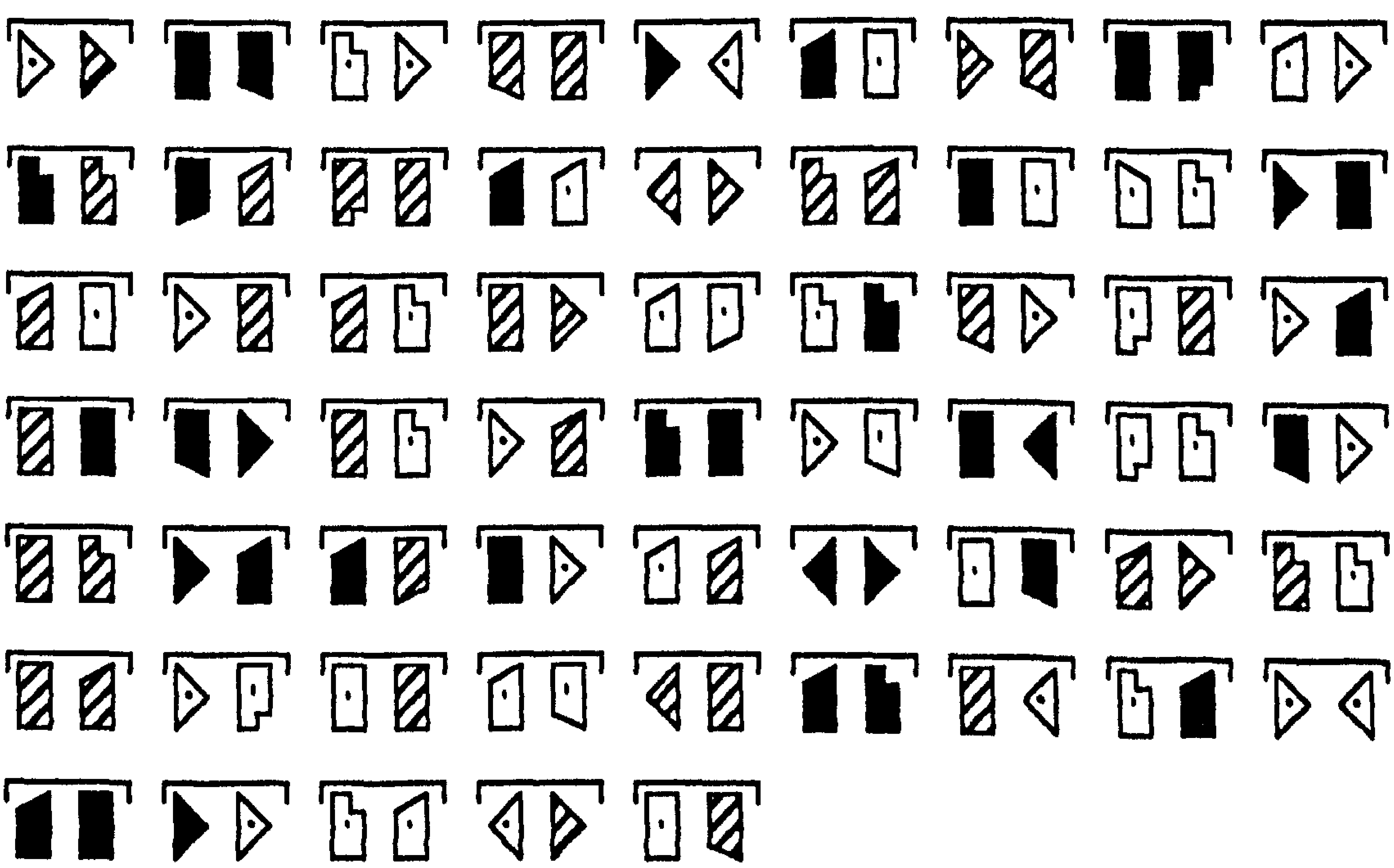
An example of one of the eight orders of presentation is listed here (read right-to-left, starting with the top line). The first symbol in each symbol-pair was the one printed at the origin of the grid (In the actual test the stimuli were continual, there was no noticeable separation between warm-up, first half and second half).

Warm-up:

First half:



Second half:



APX. XIII.30 Other Presentation Orders

Other orders were derived by dividing the first half into two groups (A, B) and dividing the second half into two groups (C, D) as follows:

First half:

Group A; the first 29 symbol-pairs
Group B; the last 30 symbol-pairs

Second half:

Group C; the first 29 symbol-pairs
Group D; the last 30 symbol-pairs

These four groups where then arranged in four different orders with the constraint that groups A and B were always adjacent, and C and D were always adjacent. Therefore the first half of the test always contained the complete set of stimulus-pairs while the second half of the test always contained the same complete set of stimulus-pairs with the opposite symbol at the origin of the grid. Each of these four different orders was then arranged progressing from the first stimulus-pair to the last (normal order) or progressing from the last stimulus-pair to the first (retrograde order). This yielded a total of eight different orders in which the stimuli-pairs were presented to Subjects as follows:

A-B-C-D (normal order) [This is the order listed in APX. XIII.20.]
D-C-B-A (retrograde order)
C-D-A-B (normal order)
B-A-D-C (retrograde order)
B-A-D-C (normal order)
C-D-A-B (retrograde order)
D-C-B-A (normal order)
A-B-C-D (retrograde order)

The four warm-up stimulus-pairs were presented either in the order listed here (see APX. XIII.20), or in the reverse order from last to first.

APX. XIII.40 Written Instructions for Subjects

The principle task is to estimate the distance required to move between pairs of kinetography (Labanotation) directions.

Each page in the test booklet contains:

-) two kinetography direction symbols;
-) a semi-circular grid (see example next page.

On each page, please proceed as follows:

-) Read the beginning direction from the symbol at the centre of the grid.

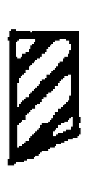
-) Read the ending direction from the symbol outside of the grid.

-) Write the ending direction symbol at a location within the grid which best represents the distance of movement from the beginning direction to the ending direction.

For Example:

 to 

If the distance to move from the beginning direction to the ending direction is small, then write the ending direction symbol within the grid at a location near to the beginning direction symbol.

 to 

If the distance to move from the beginning direction to the ending direction is far, then write the ending direction symbol within the grid at a location far away from the beginning direction symbol.

The test will be conducted in the following manner:

Proceed through the test booklet one page at a time from the beginning to the end.

Make one distance estimation for each page; write the ending direction symbol within the grid.

Please don't use excessive time for your actual writing of the symbol, just make it recognisable.

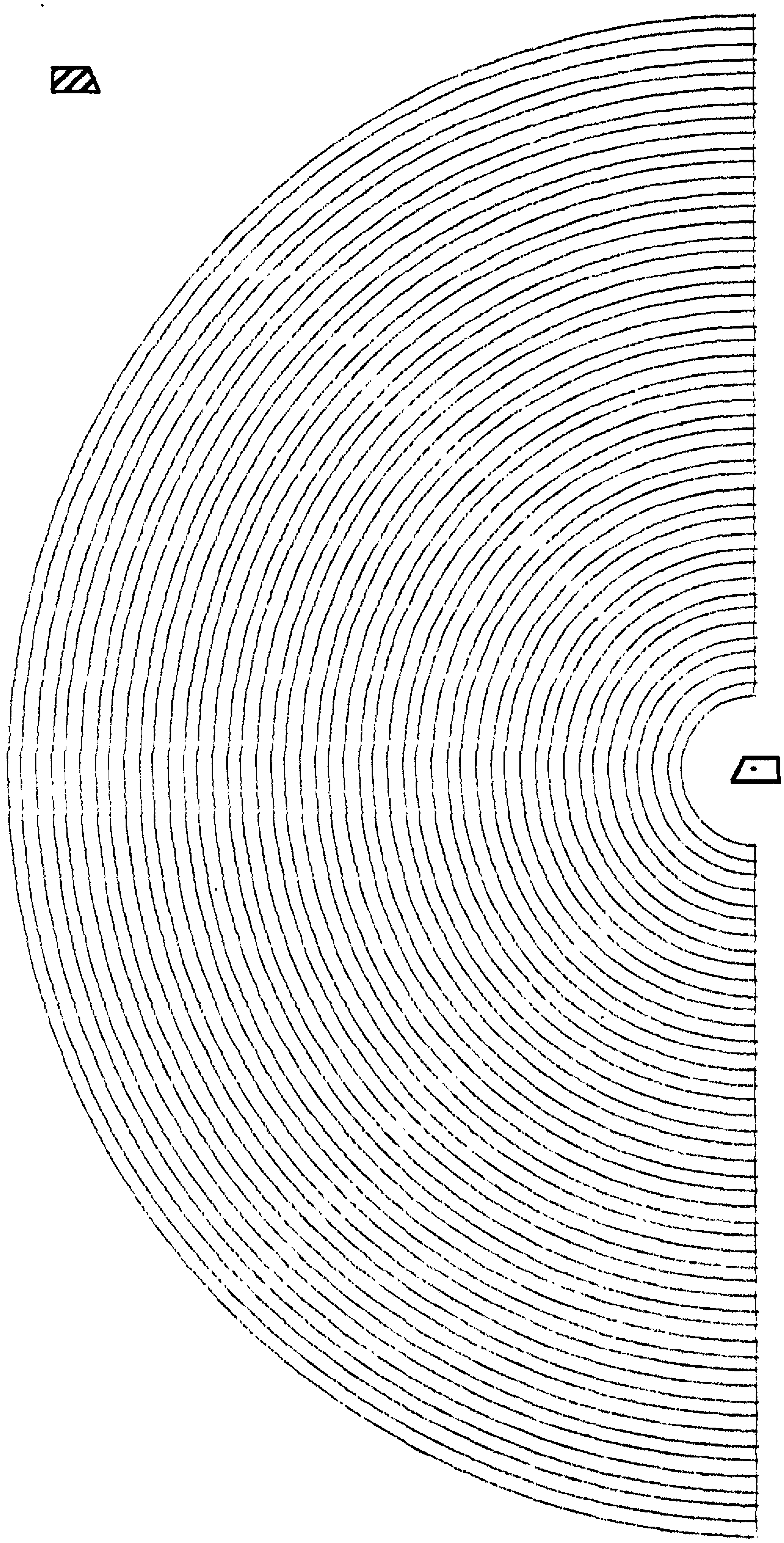
Once you have turned a page, it is finished and you are not allowed to turn back.

Pleas ask question about these instructions and the example on the next page until you understand the task requirements.

Thank you

APX. XIII.50 Example of Semi-circular Grid and Direction Symbols

(smaller than actual size; see IVA.110)



APX. XIII.60 Distance Judgements: Raw Data (millimeters)

NOTE: The first direction symbol in brackets was fixed at the origin of the grid.

61	38
31	31
33	48
48	42
47	52
45	46
39	38
38	29
54	70
89	53
92	69
37	52

21	46
21	18
45	35
41	34
25	35
39	59
44	35
45	38
46	44
53	46
36	74
59	81

96	108
44	31
67	27
80	85
91	70
30	52
58	40
30	37
88	87
76	79
101	114
33	47

84	83
56	28
63	66
75	44
49	88
51	51
90	67
37	32
70	71
52	87
98	72
48	64

67	61
33	50
65	69
41	48
48	47
42	56
61	71
74	63
73	74
98	78
118	79
48	37

61	31
26	52
65	38
44	74
45	47
57	58
63	49
35	29
52	39
78	60
69	79
48	26

66	70
29	15
68	68
51	37
41	50
58	26
71	44
40	62
50	57
47	69
77	71
71	70

49	67
18	32
68	68
45	40
68	41
32	45
62	45
62	54
45	43
59	39
81	66
73	75

81	68
33	44
68	68
47	46
45	39
53	29
62	50
60	60
42	62
74	36
119	71
73	70

67	68
26	28
68	68
61	43
32	58
32	25
54	48
63	52
59	49
68	60
86	70
72	75

58	57
122	122
68	68
45	45
51	25
29	22
30	27
17	16
34	40
24	19
53	62
66	70

61	70
126	122
68	68
44	36
29	21
23	29
28	22
15	20
28	67
21	23
79	68
74	68

121	114	107	115	115	121	121	87	121	121	121	121	97	85	81	104
122	122	121	52	120	121	125	127	123	123	123	124	61	68	43	58
131	130	129	130	131	130	131	130	130	131	130	131	108	96	97	106
84	75	63	43	54	58	64	50	98	109	101	104	92	81	43	77
69	102	46	46	59	67	65	81	117	117	119	115	38	64	101	56
120	119	122	120	120	121	121	122	120	121	121	122	74	76	82	73
58	55	60	63	74	76	84	88	109	111	108	120	67	58	54	54
60	62	80	88	90	60	64	76	116	121	122	119	66	80	88	59
26	78	83	108	107	110	78	93	121	115	123	122	51	79	91	46
57	76	100	99	102	96	106	110	122	118	120	115	98	104	110	87
99	103	82	85	93	90	118	91	122	122	121	117	111	108	124	60
127	121	127	124	128	123	125	128	125	125	122	126	105	93	95	111

64	67	67	81	57	64	65	89	66	68	66	71	64	80
31	31	47	26	35	26	30	36	32	26	31	37	46	41
65	41	69	40	38	65	69	41	66	69	67	43	67	67
38	52	41	40	52	50	33	37	46	48	36	36	30	36
43	47	46	56	49	52	40	51	49	42	43	22	43	24
40	54	67	27	56	28	56	50	52	63	50	47	25	44
40	45	58	35	41	39	73	37	49	40	58	58	49	50
33	47	32	32	41	34	36	34	35	31	40	30	36	38
69	49	57	62	57	67	54	58	68	36	41	38	48	59
53	27	54	31	50	54	37	30	33	45	42	37	27	42
75	70	76	82	81	77	67	54	82	63	57	83	108	70
69	65	63	65	72	68	74	66	66	67	66	69	64	65

13	26	20	11	59	42	17	49	71	52	60	48	23	24	45	17
35	16	15	21	15	17	16	13	21	20	21	23	21	19	22	24
49	63	38	33	32	39	25	39	27	40	32	31	42	31	33	38
18	24	18	22	16	23	20	18	44	39	28	48	32	40	17	17
20	34	17	18	30	19	21	19	29	26	31	26	31	22	29	20
23	19	21	22	25	27	21	21	21	32	22	19	21	20	23	26
56	32	29	43	36	31	33	22	37	33	31	58	36	30	49	29
18	16	19	15	17	16	15	16	17	17	17	15	19	17	17	19
27	33	38	29	39	44	38	30	27	79	40	43	39	19	38	31
19	19	19	19	24	23	21	24	28	20	20	18	17	25	20	17
39	28	113	32	33	29	32	73	51	76	73	58	57	17	46	67
67	63	35	47	37	43	36	40	45	38	43	31	51	34	44	30

16	16	19	17	19	16	18	17	38	24	26	69	50	26	66	27
29	16	24	14	19	14	17	15	17	24	16	27	28	17	17	18
30	37	36	43	39	27	41	36	41	26	43	34	38	40	30	38
38	18	23	45	27	21	17	16	32	38	20	18	35	48	46	40
18	20	28	20	26	17	17	26	19	19	19	19	19	22	48	30
19	24	19	22	21	20	24	30	21	21	32	20	23	23	20	28
41	28	44	54	23	28	35	22	45	33	53	27	26	37	31	28
15	16	17	17	16	15	17	16	18	16	17	17	17	18	17	18
24	47	49	30	38	44	35	36	40	54	30	40	50	40	32	63
17	18	49	26	28	29	25	15	23	35	20	20	22	22	18	20
83	122	80	30	92	48	34	18	76	37	83	63	65	49	89	65
26	17	18	21	18	23	36	18	46	39	34	39	20	15	33	20

17	22
18	15
41	41
26	32
20	39
25	24
48	41
35	32
43	45
19	36
53	23
47	47

21	24
19	20
53	26
17	18
34	21
20	23
61	39
41	19
39	39
35	24
84	37
79	44

28	53
15	23
40	28
18	23
21	26
21	21
35	39
33	46
46	43
30	27
36	50
45	23

34	18
14	10
28	35
21	20
21	19
19	18
38	38
16	28
45	35
36	43
22	62
52	28

30	50
26	24
47	44
38	42
33	61
55	48
84	44
36	34
55	42
48	40
51	69
72	57

58	30
26	38
34	42
42	36
52	54
41	37
47	46
34	37
30	62
43	39
88	65
84	78

38	32
19	20
49	38
45	36
64	47
33	87
62	42
30	31
47	22
60	37
107	101
79	81

51	36
33	35
44	51
42	49
40	54
31	26
32	68
66	43
44	51
36	29
90	77
48	49

17	22
17	21
36	39
18	17
21	21
20	25
40	46
18	15
26	36
25	21
20	57
39	34

18	22
22	22
46	37
21	35
18	18
24	20
40	34
18	16
62	51
28	28
55	91
33	30

15	19
23	15
25	40
21	20
20	28
23	21
45	56
18	15
34	64
29	20
110	34
41	40

18	26
18	17
38	30
16	19
27	14
20	18
39	30
17	16
36	25
23	18
43	89
24	41

20	24
19	17
32	36
41	18
15	27
24	25
38	33
14	18
38	35
20	17
30	32
30	40

18	17
15	17
38	32
17	17
33	18
19	19
33	32
20	16
80	52
24	17
29	34
49	20

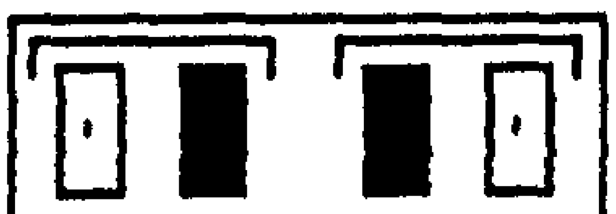
20	16
21	18
67	37
54	33
32	18
28	21
33	39
18	19
31	31
32	33
34	70
27	36

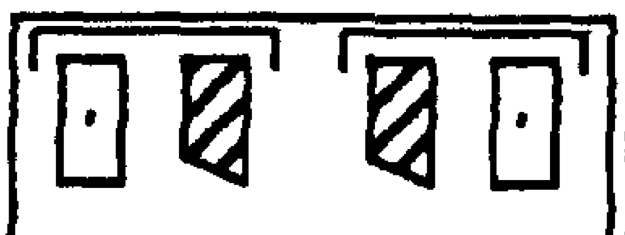
41	25
20	19
38	28
51	45
75	45
21	23
29	32
19	15
53	33
19	21
71	58
31	49

APX. XIII.70 Mean Distance Estimations for 12 Subjects: T-test Result and Significance (if any)

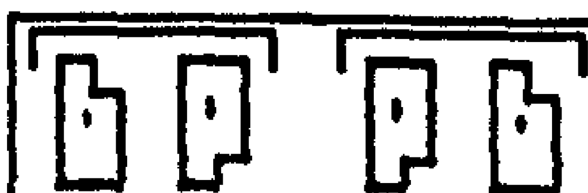
Distractor-pairs:

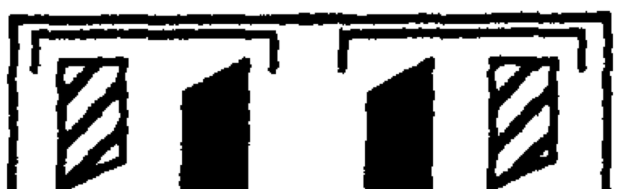
Dimensional and Diagonal radii (Cube and Octahedron central):

						
mean distance (mm)	49.7	51.2	49.8	47.8	57.3	53.7
t =	t=0.39		t=0.79		t=1.10	
p <	n.s.		n.s.		n.s.	

						
mean distance (mm)	63.1	53.6	55.2	51.3	55.8	53.3
t =	t=1.70		t=0.95		t=0.51	
p <	p<.10		n.s.		n.s.	

Dimensional, Diametral, and Diagonal axes (+ extras):

								
mean distance (mm)	89.5	96.4	93.3	89.4	99.4	97.8	100.2	98.9
t =	t=1.29		t=0.59		t=0.59		t=0.35	
p <	n.s.		n.s.		n.s.		n.s.	

								
mean distance (mm)	118.7	119.5	119.3	119.7	80.7	82.7	84.1	74.3
t =	t=0.68		t=0.31		t=0.48		t=1.09	
p <	n.s.		n.s.		n.s.		n.s.	

Same-type test-pairs:

Dimensional / Dimensional (Octahedron peripheral):

						
mean distance (mm)	51.7	49.6	56.4	48.1	52.4	52.0
t =	t=0.50		t=1.63		t=0.11	
p <	n.s.		p< .20		n.s.	

								
mean distance (mm)	52.8	48.6	53.7	49.8	49.8	47.6	50.6	51.3
t =	t=0.90		t=1.08		t=0.58		t=0.16	
p <	n.s.		n.s.		n.s.		n.s.	

Diametral / Diametral (Icosahedral peripherals):

mean distance (mm)	53.6	48.5	64.0	61.1	64.4	62.8	66.2	64.8
t =	t=0.90		t=0.64		t=0.25		t=0.27	
p <	n.s.		n.s.		n.s.		n.s.	

Different-type test-pairs;

Dimensional / Diametral (Octahedron/Icosahedron transversal):

mean distance (mm)	32.0	31.1	31.8	26.0	30.3	29.4	24.6	30.3
t =	t=0.25		t=0.82		t=0.39		t=1.26	
p <	n.s.		n.s.		n.s.		n.s.	

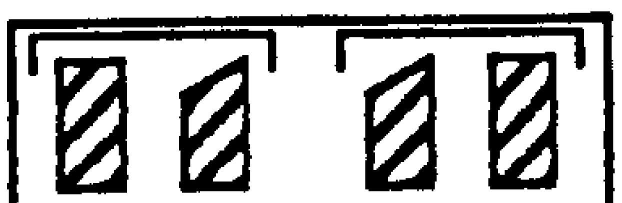
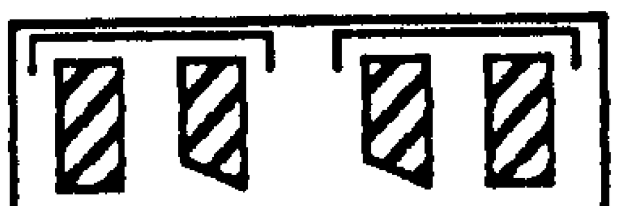
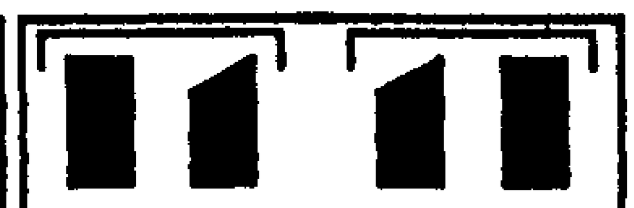
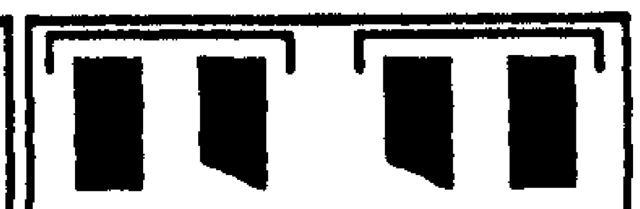
mean distance (mm)	34.8	39.3	34.8	34.8	32.4	24.8	31.9	27.9
t =	t=0.83		t=0.00		t=1.96		t=1.08	
p <	n.s.		n.s.		p< .05		n.s.	

Dimensional / Diametral (Octahedron / Icosahedron peripheral):

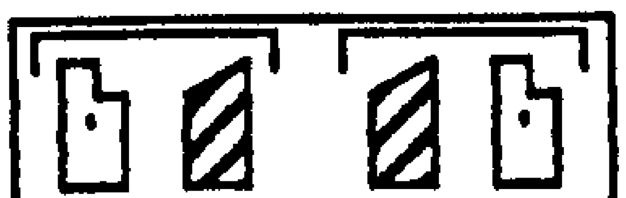
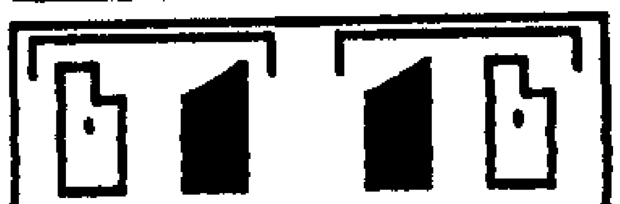
mean distance (mm)	29.7	31.6	33.8	28.3	30.5	25.2	26.3	22.1
t =	t=0.41		t=1.04		t=1.38		t=1.75	
p <	n.s.		n.s.		p< .20		p< .10	

mean distance (mm)	34.7	30.5	32.8	32.8	32.8	29.8	37.3	32.9
t =	t=0.99		t=0.00		t=0.97		t=0.84	
p <	n.s.		n.s.		n.s.		n.s.	

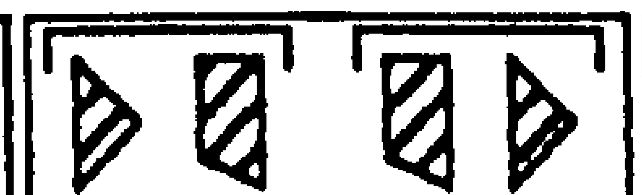
Dimensional / Diagonal (Octahedron / Cube):

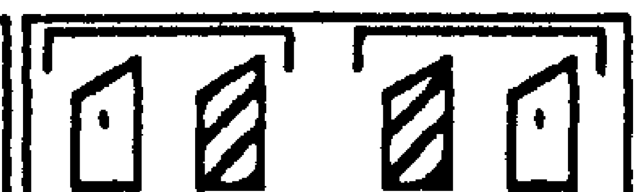
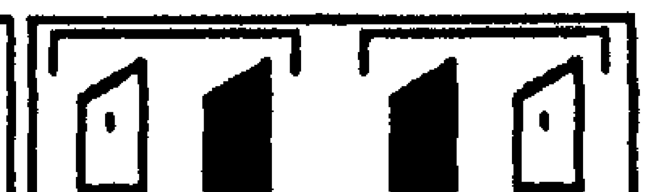
								
mean distance (mm)	32.7	33.1	41.9	27.8	30.7	33.5	28.8	29.5
t =	t=0.12		t=2.92		t=0.80		t=0.14	
p <	n.s.		p< .02		n.s.		n.s.	

								
mean distance (mm)	47.9	46.3	48.3	47.0	52.8	47.8	46.4	47.3
t =	t=0.32		t=0.28		t=0.82		t=0.21	
p <	n.s.		n.s.		n.s.		n.s.	

				
mean distance (mm)	39.6	45.4	51.2	47.3
t =	t=1.23		t=0.80	
p <	n.s.		n.s.	

Diametral / Diagonal (Icosahedron / Cube):

								
mean distance (mm)	24.8	29.5	32.1	33.7	33.7	31.0	26.6	28.6
t =	t=1.48		t=0.44		t=0.36		t=0.43	
p <	p< .20		n.s.		n.s.		n.s.	

								
mean distance (mm)	26.7	26.8	31.3	24.3	33.1	30.9	39.0	32.8
t =	t=0.03		t=2.15		t=0.46		t=1.72	
p <	n.s.		p< .05		n.s.		p< .10	

APPENDIX XIV

VARIABILITY OF PRACTICE HYPOTHESIS IN SCHEMA THEORY:

LACK OF DEFINITION OF A "GENERAL CLASS" OF MOVEMENTS

Developing a taxonomy for kinespheric categories may contribute to other areas of movement study, in particular the schema theory for motor learning developed by Schmidt (1975; 1976; 1982). Schema theory posits that movements are not stored in memory as individual items, but as members of movement categories based on the movements' core attributes. Within a "general type" of movement, particular variations are perceived or produced by distinguishing the initial sensory conditions, the selected parameters for execution (eg. how forceful, how quick), the sensory feedback resulting from the execution, and the environmental effects of the movement.

The schema theory explains how novel movements are perceived or produced by comparing them to, or deriving them from the abstracted category and is described as "currently [the] dominant psychological theory of motor learning" (Jordan and Rosenbaum, 1989, p. 753). However, the foundation of the schema, the "general type" of movement that forms the basis of the different schema families, remains undefined. This lack of definition has been identified in attempts to interpret tests of the "variability of practice hypothesis" (see below).

A major prediction for any type of schema theory was suggested by Posner and Keele (1968) who showed that Subjects who studied a wide range of variations of a prototypical abstract geometric form could more easily identify new variations of that prototype than Subjects which studied only a narrow range of prototype variations. This effect is supposed to occur because experiences with a wide range of variations increases the number of variations which might readily be considered to be members of a particular class of items. This creates a broadly applicable schema which is ready for a wide range of stimuli. Within motor learning this became known as the "variability of practice hypothesis" and predicts that experiences of a wide variety of movements within the same general class will "transfer" to (ie. be equivalent to having practiced) a new movement within that same general class, but which itself has never before been experienced (Schmidt, 1975, p. 257).

Intuitively it seems likely that a wide variety of experiences will allow a more ready perception and response to novel experiences, but experimental tests of the variability of practice hypothesis have produced mixed results. In motor tasks involving movement timing and production of force, variability of practice often does not lead to any better performance on a new variation of the task than does constant (non-variable) practice (Catalano and Kleiner, 1984; Cummings and Caprarola, 1986; McCraken and Stelmach, 1977; Newell and Shapiro, 1976; Zelaznik et al., 1978) or some Subjects demonstrate the benefits of variable practice while other Subjects do not (Johnson and McCabe, 1982; Wrisberg and Ragsdale, 1979). For a review see Lee and Colleagues (1985) and Shapiro and Schmidt (1982, pp. 118-129).

One reason that variability of practice benefits do not consistently occur may be that adults who are tested on simple movement tasks (eg. throwing a ball at a target) may have already formed a variable schema for the task from their own life's experiences. The additional practice in the experimental setting will not modify their already well developed schema. Thus, Schmidt (1975, p. 257) and Lee and Colleagues (1985, p. 284) suggest that positive effects from variability of practice may be more likely to occur with children since they have not already developed highly variable schemas for many of the movement tasks.

Studies with children have found superior performance on new tasks after variable practice on tasks involving pushing an object along a specified distance (Kelso and Norman, 1978) or throwing a ball at a target (Moxley, 1979). Though Williams and Werner (1985) found no benefit of variable practice for children on a task of crawling, jumping, running and climbing through an obstacle course.

Lee and Colleagues (1985) point out that the schedule in which the variable conditions are practiced may determine whether the benefits of variable practice occur. Battig (1966; 1972) had originally developed the notion of "intratask interference" which he later renamed "contextual interference" (Battig, 1979) to account for the effect of variable practice in cognitive tasks leading to superior performance in other similar tasks.

"Interference" from secondary tasks is usually considered to be a cause of forgetting the learning of a primary task. However, Battig found that while this interference caused slower initial learning it also led to superior long-term learning. The interference is conceived to come from the "context" of the secondary tasks:

> Items subjected to minimal contextual interference may require little processing to meet the task requirements, but this processing may be insufficient for them to be remembered after a long retention interval. Items subjected to larger amounts of contextual interference require more processing, are learned more slowly, and within most experimental paradigms may receive insufficient processing to be learned and remembered as well as those easier items with less contextual interference. Items learned well enough to overcome this contextual interference, however, typically are remembered as well as or better than under low-interference conditions. (Battig, 1979, p. 27)

Shea and Morgan (1979) demonstrated the benefits of contextual interference on a motor task consisting of moving the hand through various series of up to six locations (by "knocking down" a small "barrier" at each location) in a small (table-sized) space as quickly as possible. "Blocked" trials of variations of the motor task would have low contextual interference while "random" trials or "serial" trials have high contextual interference (ie. for motor task variations "A", "B", and "C"; blocked trials might proceed: AAAABBBBCCCC; random trials might proceed: ACBCCABACBBA; serial trials might proceed: ABCABCABCABC). Blocked practice led to faster initial learning of the motor task, but learning from random trials eventually catches up. Conversely, random trials lead to superior performance on the task after a retention interval, and also to superior performance on a new variation of the task. These results can be applied to movement education:

> Most instructors of motor skills teach one skill per session in order to avoid confusing the student, presumably giving the student the opportunity to learn the skill completely before attempting to learn a similar skill. However . . . instructors should instead teach a number of skills during each session for a number of sessions in order to achieve maximum retention and transfer [to new variations of the task] . . . instructors should be willing to incorporate this method into their teaching at the risk of seeing little progress during early acquisition trials. (Shea and Morgan, 1979, p. 187)

It was concluded that greater retention and transfer of motor skills results from serial and random learning trials because in these cases learners must entirely re-analyse and reconstruct their action plans at the beginning of each trial, thereby leading to superior learning, whereas in blocked trials the action plans are not required to be reanalysed or reconstructed after each trial but only after each group of trials (Lee and Magill, 1983). This conclusion was supported by Lee (1985) who showed that in passive performances of a task (ie. the Experimenter manipulates the Subject's passive arm so that no active action plans are required by the Subject) that no learning superiority resulted from random or serial trials. Thus, it is the multiple cognitive analyses required by random or serial practice schedules that cause their superiority over blocked practice, not the practice schedules themselves.

Contextual interference has been used to reinterpret the results of variability of practice experiments suggesting that when variable practice occurs with a random or serial schedule it results in superior performance on transfer to a new variation of the task (Lee and Magill, 1983; Lee et al., 1985). However, random trials of variable practice do not always lead to superior performance on transfer to a new variation of the task (Catalano and Kleiner, 1984; Johnson and McCabe, 1982), or this superiority of performance does not last over a retention interval (McCraken and Stelmach, 1977). In addition, a blocked variable practice schedule sometimes does lead to superior performance on transfer to a new variation of the task, equal to random or serial practice schedules (Newell and Shapiro, 1976).

Thus, no consistent effect of variability of practice studies has been demonstrated. The major problem in evaluating the variability of practice hypothesis has been identified as the lack of criteria for determining when movements belong to the same schema family or not (Newell, 1991, p. 221; Sheridan, 1984, p. 79; Van Rossum, 1980).

In practice it has been left up to the personal intuitive judgment of the experimenter as to whether movements are variations of the same schema. Schmidt (1975) referred to a schema family as containing movements with the same "basic pattern" and which therefore belong to the same "general type" (p. 235) or the "same class" (p. 257). The criteria for determining this membership is neglected. The closest definition given is that movements of the same general type are those which attempt to satisfy the same goal (p. 235).

Shapiro and Schmidt's (1982, p. 136) more recent definition is that movements within the same class will have the same relative timing between elements within the motor sequence. This relative timing is termed "phasing" and has been identified to be an invariant aspect of a "motor program" (preprogrammed sequence of motor actions). In their example they suggest that throwing balls of different weights may each be related to a different ball-throwing schema. However, this definition appears to be so restrictive as to limit the breadth of a schema class to such an extent as to lose its benefit of being flexibly applicable to a range of movements.

Determining categories of kinespheric form may contribute to this problem of defining what constitutes a general class of movements.

APPENDIX XV

VIRTUAL FORMS

APX. XV.10 Spatial Tension

The notion of a spatial form being embodied as a "tension" has been used in slightly different ways by different authors but in general it refers to the perception of a spatial line or a connection between at least two separate locations. Spatial tensions have been conceived to occur as an objective reality within the body or as a subjective perception of a connection between two loci across empty space. These might be referred to as "physical spatial tension" and "perceptual spatial tension".

APX. XV.11 Physical Spatial Tension.

Physical tension is a measurable quantity which can be created by a variety of forces. The essence of physical tension is always spatial since it refers to a stretching or a compressing of some substance between at least two locations. The "tensile strength" is a measurement of the amount of stretch that a material can withstand before it breaks. The "surface tension" of a liquid is a measurement of the force required to pull an object out of that liquid (Collins 1986). Muscular tension tends to cause the muscle to shorten and pull its ends closer together along its line-of-pull.

Bodily equilibrium is created by equalised and opposing tensions. Newton's first law of physics can be stated as "When the total of all forces acting on an object is 0, the body is in a state of equilibrium" (Rasch and Burke, 1978, p. 116). That is, the pushing or pulling forces acting on the body in various directions all equalise each other so that their sum is zero and therefore the body does not move.

In choreutics this is stated as the "law of equilibrium" which posits that "The three-dimensionality (plasticity) of our body requires that each true equilibrium placement shall be *tensioned* in three directions over the supporting vertical" (Laban, 1926, pp. 17-18 [italics mine]) or that "Movements with counter-tensions are generally stable" (Laban, 1966, p. 94). Three-part stabilising tensions are sometimes referred to as "chordic tensions" or "balanced tension shapes" (Bartenieff and Lewis, 1980, pp. 107-108). Maletic (1987, p. 75) reiterates that the "principles of counter-tension", or "counter-movement" are often used in choreutics synonymously with "opposition" such as reaching into opposite directions in order to maintain equilibrium. Similarly, Laban (1963, p. 27) describes opposition as the "bodily tension which arises from the relationship between the changing spatial inclinations of the path and the demands of balance".

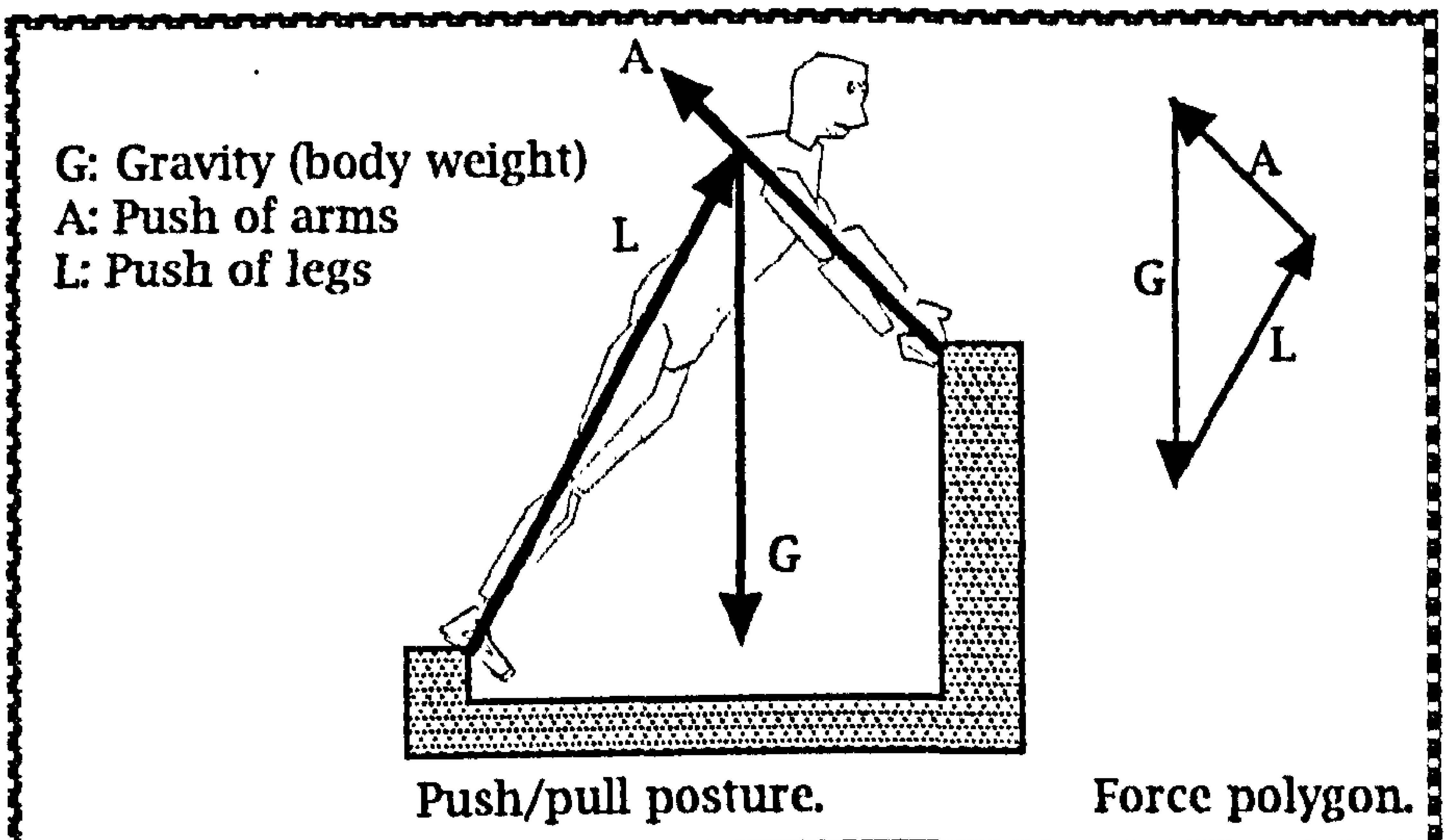


Figure APX. XV-1. Free-body diagram (adapted from Dempster, 1961, p. 110).

Dempster (1961) discusses the history and application in studies of mechanics in which the different forces acting on a body can be represented graphically as a collection of lines with arrows. These analytical aids are known as "free-body diagrams", "force diagrams" or "force polygons" (p. 86). Arrows indicate force vectors which "represent the sense, direction and magnitude of all applied environmental forces such as . . . pulls, pushes, wind resistance, buoyancy effects, gravitational force or magnetism" (p. 87), including the "direction of pull" of muscles (p. 126) (Fig. APX. XV-1). In accordance with Newton's first law of.physics, when the collection of simultaneous forces equally counteract each other, then the body is at rest:

> When the body is regarded statically as at rest, the various forces of the diagram must be in equilibrium; that is, forces directed toward the right must be balanced by forces directed toward the left, and upward forces must be balanced by downward forces [etc.]. (Dempster, 1961, p. 88)

These directional forces applied to an object are identical with the concept of physical spatial tension since they specify the direction and magnitude of the pulling and pushing forces acting upon an object. For the sake of simplicity the force vectors are usually represented in a two-dimensional plane and so the configuration of all the directional forces can be arranged into a "force polygon" (Dempster, 1961, p. 86). However, the same approach can be extended to three-dimensions (p. 88) and in this case might be considered as a force polyhedron. This three-dimensional arrangement of force vectors is identical to the choreutic "chordic-tension" (see above).

There are also an abundance of polygonal and polyhedral tension networks present in naturally occurring structures. These typically occur by dividing the space (either two- or three-dimensional) into equal portions when each member of a group seeks to be equidistant from every other member in the group.

Because of the incredibly large numbers of examples, only a brief overview can be included here. One of the most basic tension networks upon which all living tissue and many minerals are constructed is the tetrahedral form of carbon. The chemistry text by Brady and Humiston (1975) is especially good at picturing the many varieties of atomic and molecular polyhedral structures which result since electrons and/or atoms seek to maintain the maximum distance from all other electrons and/or atoms within the element or compound. This is known as the "electron pair repulsion theory" according to which "electron pairs would like to be as far apart as possible so that the repulsion between them is an a minimum (pp. 464-465). These "electrostatic repulsions" (p. 466) between electrons creates polyhedral structures of atoms and groups of atoms. For example, a water molecule is organised into a tetrahedral structure (Fig. APX. XV-2) and the electron paths in a neon atom have an octahedral arrangement (Fig. APX. XV-3). In other cases when identical atoms do not share electrons their structure is determined by the closest packing of spheres (p. 191).

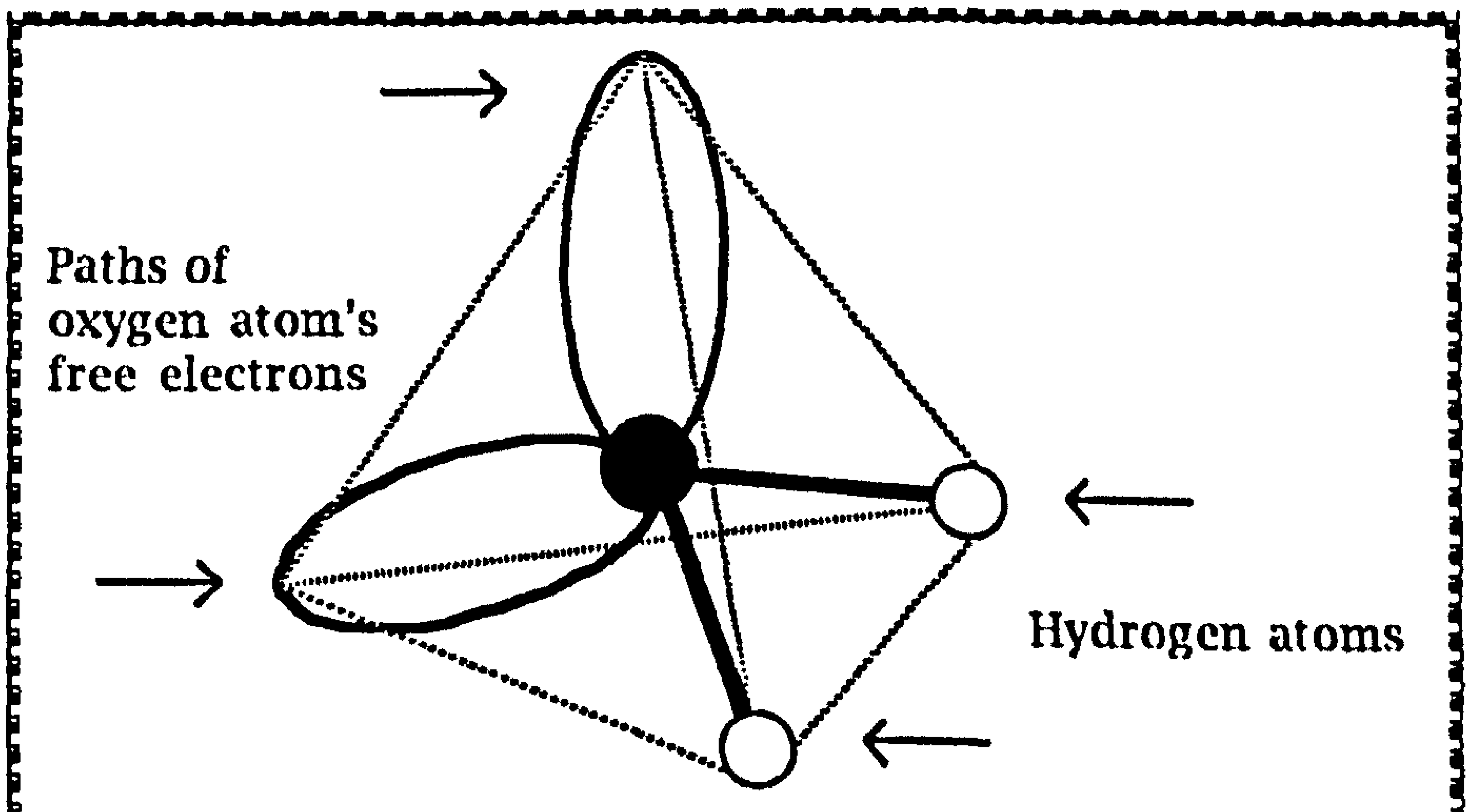


Figure APX. XV-2. Tetrahedral molecular structure of water (H_2O) (Adapted from Brady and Humiston, 1975, p. 468)

Electrostatic repulsions and the closest packing of spheres are principal causes in the creation of polygonal and polyhedral structures in natural forms. These are well known in the structures of crystals (Cartmell, 1971; Loeb, 1966; Wells, 1984) and also occur in crystallised hemoglobin (Drabkin, 1975). The closest packing of circles creates triangle and hexagon arrangements (Fig. APX. XV-4), which contributes to forming the well-known hexagonal structure of bee's honeycombs. Four spheres pack closest together into a tetrahedral arrangement (Fig. APX. XV-5). As spheres are added octahedral (six spheres), cubic (fourteen spheres), icosahedral (twelve spheres), cuboctahedral (thirteen spheres), and dodecahedral (thirty-two spheres) structures are formed. These are well pictured by Critchlow (1969, pp. 7-9). The packing of the greatest number of spheres in the smallest amount of space results in the icosahedral and dodecahedral shapes of viruses (Doane and Anderson, 1987; Maramorosch, 1977), and irregular polyhedral shapes of metal grains, soap bubbles, and biologic cells (Smith, 1981). An abundance of natural polyhedral and polygonal forms are illustrated by Ghyka (1977, pp. 87-110) and in the monumental work by Thompson (1961). An ingenious series of experiments by Hans Jenny (1974a; b) reveals the spatial tensions produced by physical vibrations of sound waves as can be seen in the polygonal and polyhedral patterns produced by vibrations in materials such as sand, water drops, soap bubbles, and drops of mercury.

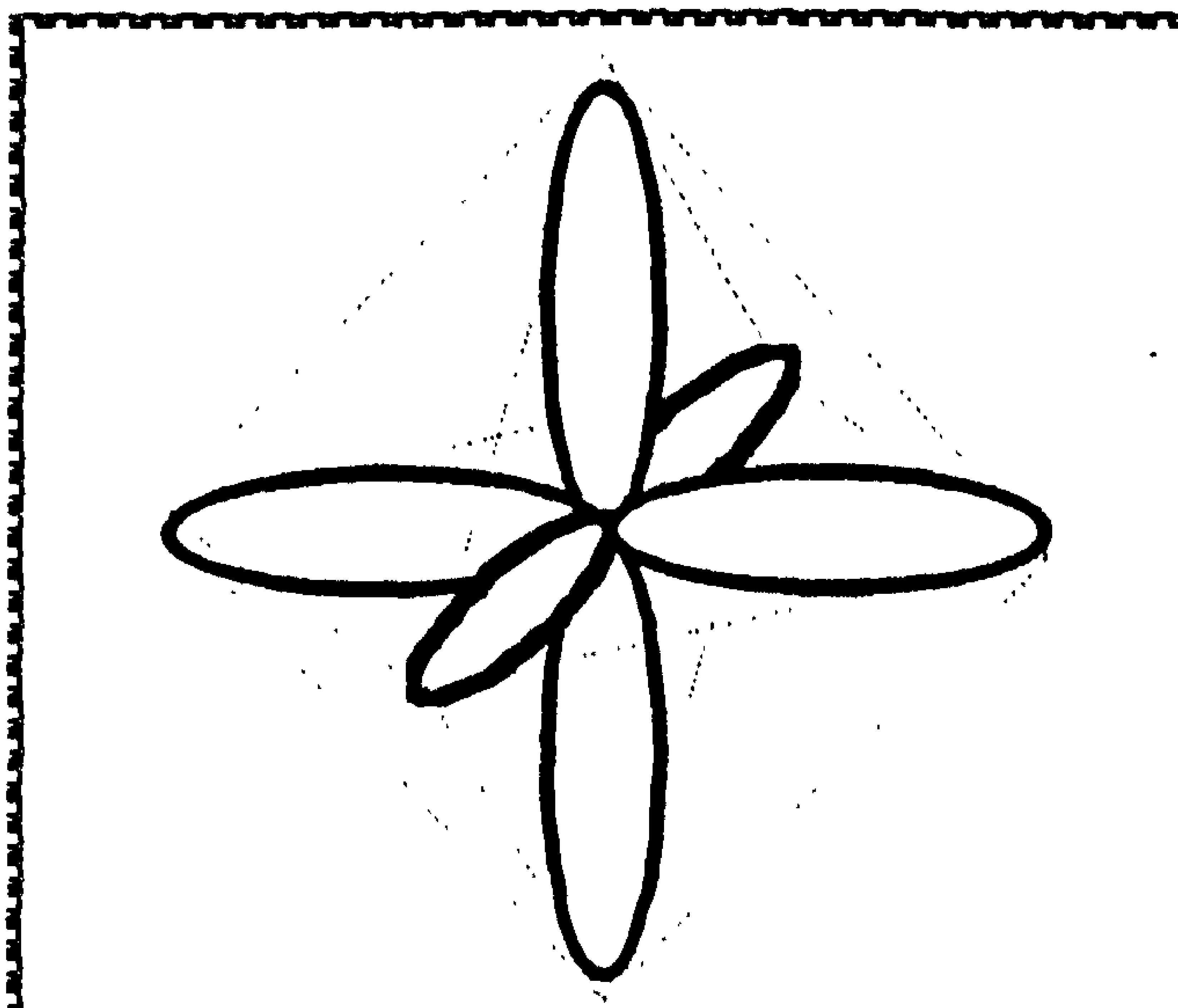


Figure APX. XV-3. Octahedral arrangement of electron paths in a neon atom.

This brief review of physical tensions in mechanics and in natural structure reveal the basis in physics for the conception of physical spatial tension in choreutics. In all cases polygonal or polyhedral structures occur when the attraction/repulsion forces (ie. "tensions") cause a group of items to be evenly distributed in space. The philosopher Langer (1953) criticised Laban's conception of spatial tensions on this same ground, asserting that "the relation of the created 'tensions' to the physics of the actual world involves him [Laban] in a mystic metaphysics that is at best fanciful, and at worst rapturously sentimental" (p. 186). This statement reveals Langers' ignorance of the physical tensions discussed above. It is probable that Langer was referring to perceptual spatial tensions, but these have also been identified as having a psychological reality even if they may not be physically "real" (see below).

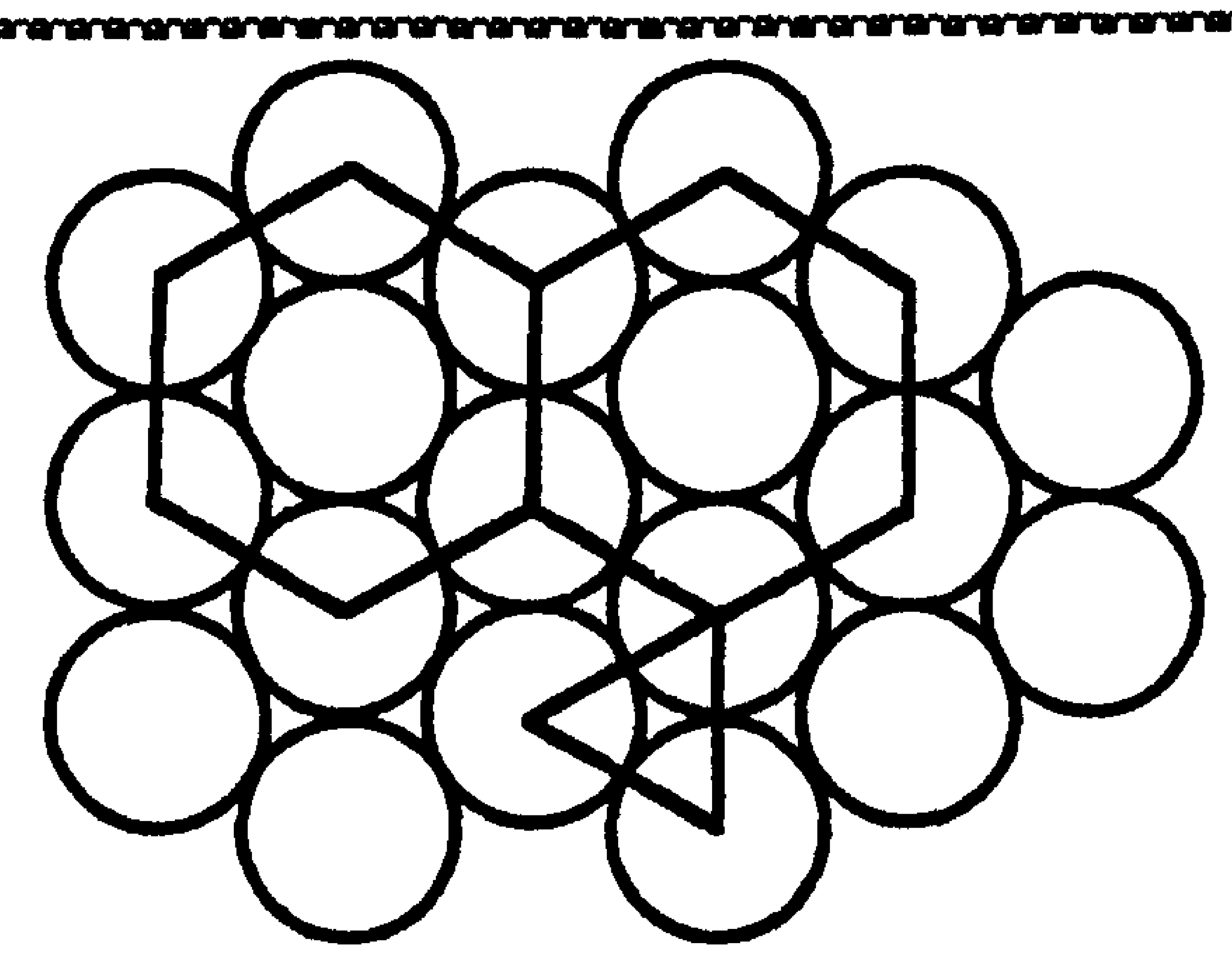


Figure APX. XV-4. Circle packing.

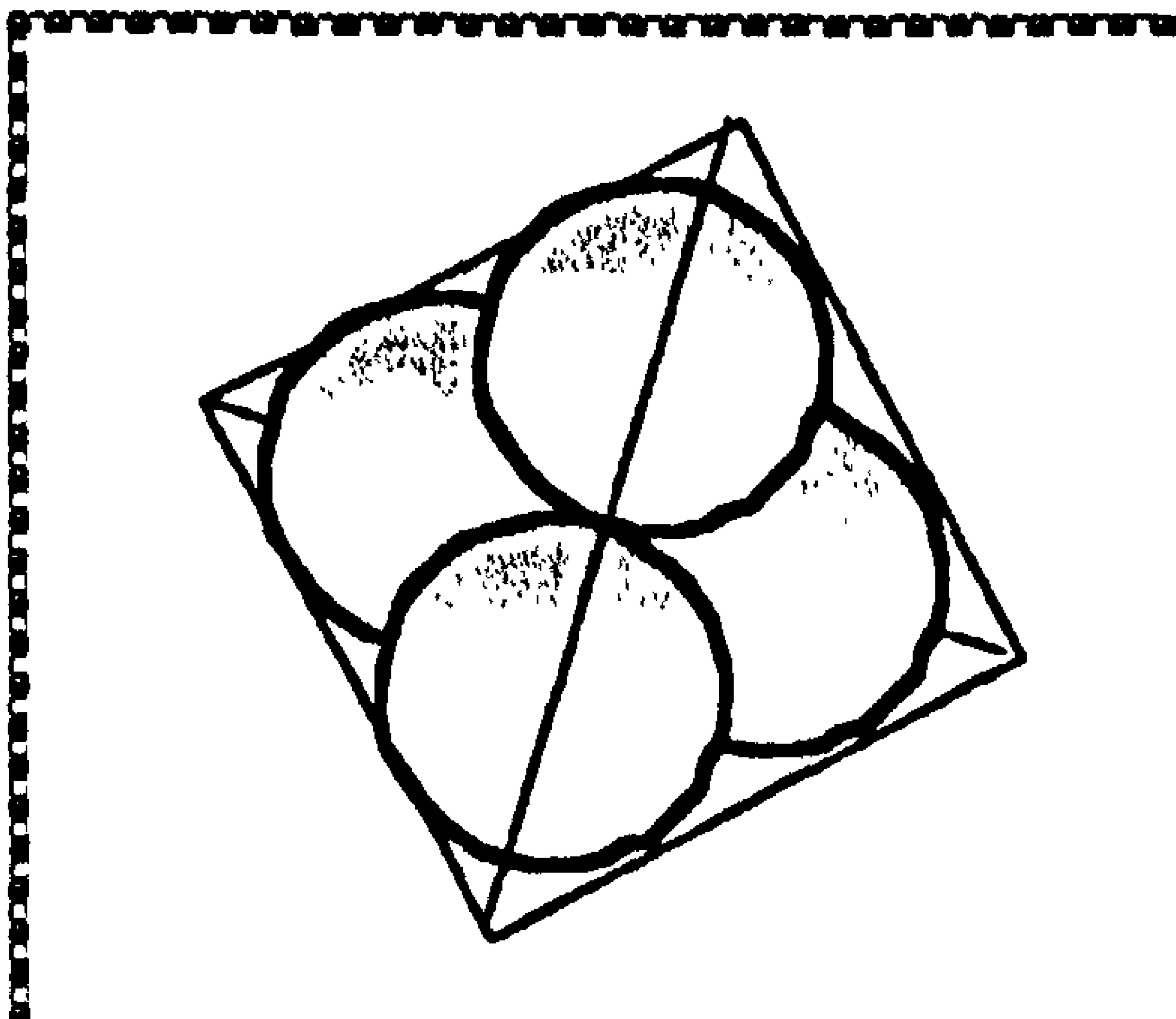


Figure APX. XV-5. Four spheres pack into a tetrahedron.

APX. XV.12 Perceptions of Central, Peripheral, and Transverse Spatial tensions .

Spatial tensions (either physical or perceptual) are categorised as exhibiting a central, peripheral or a transverse relationship to the centre of the kinesphere (Bartenieff and Lewis, 1980, p. 107; Laban, 1966, p. 68). These can be defined objectively as follows: Central tensions connect between the centre and the peripheral edge of the kinesphere. Peripheral tensions connect along the circumference of the kinesphere. Transverse tensions connect through the space between the centre and the periphery. Central, peripheral, and transverse tensions can also be described expressively as "radiating", "creating a sense of edge", and "traveling between the periphery and the center" respectively (Bartenieff and Lewis, 1980, p. 107); or as "penetrating the kinesphere", "creating an edge or boundary to the kinesphere" and "cutting through the kinesphere" respectively (Groff, 1987, p. 29).

APX. XV.13 Tension as Intention and Extension.

Descriptions, of central, peripheral, and transverse tensions are illustrative but do not define what is exactly producing the "tension" and how this is different than a kinespheric path or a pose. Spatial tension is sometimes considered to be the primordial element within all kinespheric forms, that is, as the observable exterior quality of the "intention" to execute a kinespheric formation.

Laban (1966, p. 20) seems to refer to "tension" as "an awareness of the extended arms and legs" which are moving towards a number of directional "pulls". Ullmann (1975) uses "extension" in the same way to describe the "spatial tensions" of body movement (p. 124) in which the "characteristic quality of space is extension" (p. 121). This account appears to link together 1) exterior spatial directions, and 2) interior kinesthetic sensations produced in the body as a result (and the cause) of movement into these directions. Particular kinesthetic sensations can be associated with particular exterior directions and these may occur as a unified perception. Thus "spatial tensions" can be seen as the exterior spatial manifestation of kinesthetic sensations.

Bartenieff and Lewis (1980) appear to concur with this inner/outer dichotomy. The inner kinesthesia and the outer directions lead to the "kinesthetic experience of spatial tensions" (p. 29). They use the term "spatial shaping" to refer to "creating [exterior] trace forms of spatial tensions" (p. 107):

> The muscle pull on the bones . . . can be called an *inner* shaping process. [As opposed to] Spatial intent [which] exerts a pull of the body-reach possibilities to create an *outer* process of shaping space. . . .
>
> In the spatial shaping process, the [interior] muscle pulls . . . create [exterior] lines of different spatial designs which reflect the condensations and expansions of body-spatial tensions. (Bartenieff and Lewis, 1980, p. 103 [italics theirs])

That is, the inner muscular pulls and the outer spatial designs are reflections of each other. The intention to move in a particular direction is reflected (more accurately: "translated") into the tensions of particular muscles, tendons, joints, and skin. This is different from "body shaping" which refers only to generalised inward / outward movements (eg. during breathing):

> General going-toward-or-away-from-the-body movements, for example, simply condense space or disperse it. The degree of spatial tension and [spatial] shaping in such general movements is minimal. . . .
>
> [However] As soon as any part of the body relates to a spatial intent, the beginnings of spatial tension occur. . . . [A spatial] tension is created between the object [ie. the intent, the goal] and the initiation of the movement in the body . . .
>
> [Thus] Spatial intent is the key to the difference between body shaping and spatial shaping. (Bartenieff and Lewis, 1980, p. 108 [these quotes have been rearranged, they do not appear in this order]).

Similarly, Groff (1987, p. 29) describes spatial tension as a "relationship of the body and the limbs such that there is an active relationship between the parts moving and the center of the body" and an "active relationship of the body to the space around it . . . [which] suggests an active attitudinal investment in how the body is relating to the kinesphere". That is "spatial tension is the external manifestation of an inner attitude toward the use of the kinesphere".

This close relationship of the terms "tension", "extension", and "intention" agrees with their etymologies, all being derived from the Latin root *tendere* ("to stretch"). "Tension" is closest to the root, referring to the general stretch or strain. "Extension" adds the prefix "ex-" (out of) referring to the interior bodily-kinesthetic stretching outwards. "Intention" adds the prefix "in-" (into, towards) referring to the exterior spatial goal or aim to be stretched towards (Collins, 1986).

According to the "intention" to move in a certain direction, spatial tension is sometimes considered to be inherent to the particular path or pose. Thus, Bartenieff and Lewis (1980) refer to "trace-forms [ie. paths] of spatial tensions", that "spatial tensions can be ordered in terms of the three primary spatial paths" (central, peripheral, transverse) (p. 107), and to "spatial shapes [ie. poses], with inherent spatial tensions" (p. 108). Paths are discussed as being examples of spatial tension:

> Pulling a fishing net out of the water is a central pulling tension. A Japanese dancer opening a fan, moving it in a half-circle away from the body, moves in a peripheral spatial tension . . . Pitching a baseball in a wide arc across and up . . . is an example of a transversal spatial tension . . . (Bartenieff and Lewis 1980, p. 107)

Contrary to this notion of spatial tensions being inherent to particular paths or poses, other authors assert that spatial tension is separable from these. However, an objective method to distinguish the path or pose from the tension is not provided (Groff, 1987).

APX. XV.14 Kinetic Muscular Chains; Connectedness; Coordinative Structures .

Spatial tension and opposition within the body is also described as "connections" such that multiple body-parts do not operate in isolation but are "connected" into a single coordinated system. For example:

> [When] a baby lifts his head up for the first time he will soon try to support himself further by pushing down on his arms of elbows and forearms. He creates the vertical countertension which leads to uprightness. (Bartenieff and Lewis 1980, p. 105)

Similarly, when trying to push a heavy piece of furniture the mover must "create the downward push into the floor against the upward-forward pattern that would serve as a countertension push". If this countertension is not created by the two simultaneous pushes (extensions) in opposite directions, then the mover can only lean with her whole body but cannot generate any directional force (Bartenieff and Lewis, 1980, p. 107). These opposing pushes do not consist only of isolated "muscle tensions that appear in the interplay of opposing muscle groups", but rather to "large configurations [of muscles] that can be described as kinetic, muscular chains" (p. 105). A kinetic muscular chain is "the sequence of muscles used in a movement" (p. 21) and their "connection" between different body-parts (p. 114). This is similar to the notion in motor control research of a "biokinematic linkage" (Tuller et al., 1982) or a "kinematic chain" (eg. Morasso, 1986). For example, "A 'limb' is a kinematic chain, ie. a sequence of articulated linkages which originate from a 'reference body' [eg. the pelvis] and terminate with an 'end effector' [eg. a foot]" (Baratto et al., 1986). A "link" is an engineering concept used in kinematic systems which can be applied to body movement by considering a "body link" to consist of an imaginary line which spans the distance between the centres of two joints (Dempster, 1955). However, "connectedness" implies more than just a physical joining of a series of links:

> Connectedness . . . allows the flow, the movement impulse, to pass through the body in such a way that complete activation can be realized most efficiently. . . . connectedness is more than muscles traveling over the joints to hook up two bones, it is the activated chains, configuration of connections that control the movement process. (Bartenieff and Lewis, 1980, p. 21)

This notion of connectedness is identical to the motor control concept of a "coordinative structure", also referred to as a "muscle linkage" (eg. Tuller et al., 1982). This theory posits that coordinated body movement is not controlled by isolated contractions of individual muscles but by "a group of muscles often spanning several joints that is constrained to act as a single functional unit" (p. 253). A coordinative structure is an organisation whereby groups of muscles actively respond to and cooperate with each other rather than acting independently. Groups of muscles which cooperate within a "single functional unit" could be said to be members of a "kinetic muscular chain", to be "connected" and thus to be creating a countertension between the two ends of the linkage (see IIIB.60).

APX. XV.15 Perceptual Spatial Tension.

The notion of a perceptual spatial tension can be used to refer to a perceived connection between two locations across "empty" space. this type of spatial tension is a "virtual" form in that it occurs as a result of a subjective perceptual phenomenon rather than a physical reality. The question for analysis is then, what are the objective factors which may tend to elicit the perception of a kinespheric tension?

Groff (1987, p. 29) describes how "spatial tension is indeed an important and valuable characteristic of movement" but that "even though we know it when we see it, it is difficult to try and explain what it is that is giving the movement the quality we see". Preston-Dunlop uses the term "spatial tension" to describe "imagined tensions between two body parts or two people" (1980, p. 89), or as "a way of moving, or of holding a position, which causes a connection to be seen. . . [between two loci], making perceivable an illusory line" (1981, p. 54). Similarly, Hutchinson-Guest (1983, pp. 128-129) describes this as an "awareness" between two "points of interest" which causes a "line of energy" to be perceived which connects these two points together.

In Kirstein and Stuart's (1952) comprehensive drawings of ballet movements and positions many tension-like connections are illustrated between different body-parts, both within the mass of the body's pose and also connecting body-parts across empty space, especially in the drawings of the "theory of design" (pp. 81, 104, 106).

In studies of perception of art, Arnheim (1974, pp. 10-16) describes how observers never see a visual stimulus in isolation but always perceive a "play of attraction and repulsion" among the individual stimuli within an array of stimulation:

> What a person or animal perceives is not only an arrangement of objects . . . It is, perhaps first of all, an interplay of directed tensions . . . they have magnitude and direction, these tensions can be described as psychological "forces". (Arnheim 1974, p. 11)

Arnheim (1974) refers to these perceptual tensions as the "'induced structure'" of the stimuli (p. 12) and that these "perceptual inductions" are derived spontaneously and so differ from "logical inferences" such as conscious interpretations (p. 13). Arnheim's work has been reviewed in this research within the review of prototypical locations and orientations (see IVA.55). In essence, a tension will be perceived between the actual location of an object and its prototypical location. Similar results were found in spatial cognition experiments by Huttenlocher and Colleagues (1991).

Rogers (1969) identified perceived spatial tensions in sculptures in which "it is not the material components of the sculpture that are the chief concern but the ways in which they are related to each other and to their surroundings" (p. 26). Certain "spatial relations" are evident consisting of directional connections which "come into being across space between components [of the sculpture] that are not physically connected and give rise to tensions between them" (p. 30). In these cases the physical mass of the "solid components are used primarily in order to define [the empty] space" (p. 70), and so the tensional connections "exist *between* the solids rather than *in* them" (p. 77 [italics his]).

Many psychological experiments have demonstrated that separate stimuli are perceived to be connected together when in fact they are not. This was especially evident in Gestalt psychologists' experiments working with briefly presented visual stimuli (Koffka, 1935, pp. 148-171; Lindemann, 1922; Wertheimer, 1923) or tactile stimuli (Von Frey, 1923). The Gestalt principles of perceptual organisation were developed from these findings which describe the configurations which tend to induce tensional connections between different stimuli (eg. according to proximity, similarity, continuation, closure, common fate, etc.; see IVB.27). Indeed, visual stimuli which are nearby and have similar shapes are so automatically grouped that Subjects find it more difficult to perceive either of the stimuli in isolation rather than connected together (Pomerantz and Garner 1973; Pomerantz and Schwaitzberg 1975).

In another line of research, groups of dots with similar movement paths are automatically perceived as connected into a single solid object (Cutting and Proffitt, 1982; Johansson, 1950; 1958; Johansson et al., 1980). Complex paths of individual dots are also immediately perceived as connected together and recognised as a human body in motion rather than the dots being perceived as separate (Cutting, 1981; Johansson, 1973).

Preconceptions about the uses of particular body-parts may also encourage them to be perceived as part of a spatial tension. This could be described as an ingredient within the body-part's schematic representation of which the typical effect can be stated as; you see what you expect to see (eg. Mandler, 1984). For example, the hands and the eyes are typically used to contact other objects in the environment and so this type of usage comes to be expected. Therefore they are particularly susceptible to being perceived as forming a spatial-tension between themselves and another object or body-part. For example, when the hands reach toward an object, or the eyes focus on an object, a spatial tension will likely be perceived between the hands or the eyes and the object.

This type of research reveals that the spatial tensions perceived as connections between separate stimuli are so automatic within perceptual processes that they cannot be ignored. These tensional connections become the essence of the "reality" which is perceived, rather than the "reality" which might be measured with a ruler. Langer's (1953) objective realism leads here to state that "All forces that cannot be scientifically established and measured must be regarded from the philosophical standpoint, as illusory" (p. 188). This obviously refers only to the physical sciences since experiments in the behavioral sciences provide overwhelming evidence of the psychological reality of "illusory" forces. Arnheim summarises this issue:

> Whether or not we choose to call these perceptual forces 'illusions' matters little so long as we acknowledge them as genuine components of everything seen. . . . [These forces] are 'illusory' only to the man who decides to use their energy to run an engine. Perceptually and artistically, they are quite real. (Arnheim, 1974, pp. 17-18)

APX. XV.16 Physical-space / Perceptual-space Interactions .

Returning to the association between inner physical muscular tensions and outer spatial lines (see above), Bartenieff and Lewis (1980, p. 103) described how "[interior] muscle pulls . . . create [exterior] lines of different spatial designs which *reflect* the . . . [interior] body-spatial tensions" [italics mine]. A kinesiological analysis of the interior muscle tensions involved in producing exterior spatial patterns reveals that the interior physical muscular tensions are approximately parallel to the exterior perceived spatial tensions.

For example (Fig. APX. XV-6), when opening the two arms simultaneously from the front towards the two sides (horizontal extension) a peripheral or a transverse spatial tension may be perceived as a connection across the empty space between the two hands. This perceived line of tension is reflected into the physical tension of the contracting muscle linkage across the upper back* and the tension of the stretching muscles across the chest.# The line-of-pull and the line-of-stretch from the

---

* Muscles contracting across the back during horizontal extension include the posterior deltoid, infraspinatus, teres minor, teres major, latissimus dorsi, and for

Muscles stretching across the chest during horizontal extension include the pectoralis major, anterior deltoid, coracobrachialis, short head of biceps, pectoralis minor and serratus anterior.

entire muscle groups involved will be roughly parallel to the exterior spatial line created by the motion of the two hands. This can properly be referred to as a "translation" (rather than "reflection") of the exterior perceived spatial tension to the interior physical muscular tension.

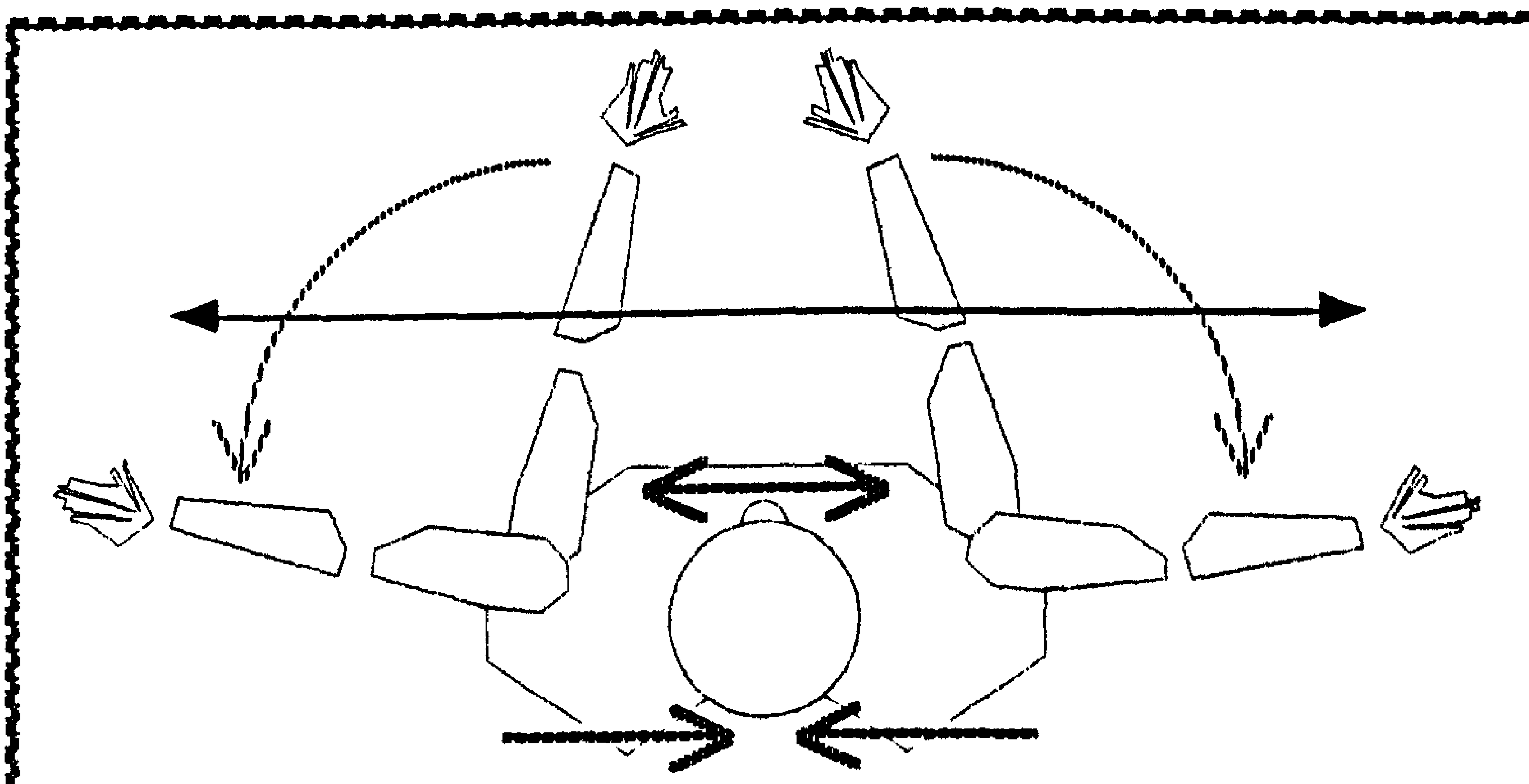


Figure APX. XV-6. Exterior perceived spatial tension translated into interior physical muscular tension (see text for explanation).

In a different situation the perceptual spatial tension might disagree with the physical muscular tension. For example the combined lines-of-pull and lines-of-stretch in the physical muscular tension may raise the arms vertically upwards but since the the hands are in proximity and are similar, and if the palms are facing each other, they may elicit perception of a lateral line connecting the two palms.

APX. XV.17 Higher-order Tension Networks.

The simplest tension is really a countertension since it consists of a stretching or a pulling connection between two different locations. Bartenieff and Lewis (1980, p. 105) describe that in its simplest form "moving in the kinesphere away from the body into even one direction causes a tension between the body and the point reached". Groff (1987, p. 29) concurs "that the quality of spatial tension does rely on the concept of countertension". And Preston-Dunlop (1984, p. x) defines spatial tension as "a tension between two parts, so that it is seen as counter-tensioned force".

Multiple spatial tensions can be organised into higher-order networks. The simplest of these is the 2-part countertension (Bartenieff and Lewis, 1980, p. 114; Preston-Dunlop, 1980, p. 115). If three or more simultaneous tensions occur in the same plane they can be conceived as polygonal networks shaped like triangles, quadrangles, entangles etc. (Bartenieff and Lewis, 1980, p. 113; Laban, 1966, pp. 19-20).

If three or more simultaneous tensions occur in different planes they can be conceived as polyhedral networks shaped like a tetrahedron (Bartenieff and Lewis, 1980, pp. 47, 97-99; Laban, 1966, p. 20) or referred to as a "chordic tension" (Bartenieff and Lewis, 1980, p. 116) or a "four-tensioned star" (Laban, 1926, p. 88).

By compiling tension networks together or considering the many simultaneous tensions exhibited in multiple body-parts, Laban arrived at even higher-order polyhedral networks. The arrangement of locations within these networks provides various equidistant divisions of three-dimensional space and so are used in choreutics as the overlying "grid" or map according to which particular paths and poses are specified (see IIIC).

APX. XV.20 Spatial Projection

Another mode of embodying kinespheric form was identified by Preston-Dunlop (1981, pp. 55-57) when it was observed that a kinespheric form performed by a dancer "was clearly not contained in the body but appeared to fly off into the space beyond her reach". This was termed "spatial projection" and defined as "a line or a curve, which continues beyond the body into the kinesphere or on into the shared space".

Creating the appearance of a spatial form projecting beyond the body is similar to the concept of spatial tension (see above). Preston-Dunlop (1981, pp. 55-57) describes how spatial tension is a "relationship through space between two parties" and that projection is a relationship "between one party and infinity". Similarly, Groff (1987, p. 31) observes that the "qualities of spatial tension can be projected into the general space". Thus, projection is a "virtual" form in that it is observed as a result of a subjective perceptual phenomenon rather than a physical reality. The question for analysis is then, what are the objective factors which may tend to elicit the perception of a kinespheric projection?

APX. XV.21 Projection elicited from Dynamics.

The perception of spatial projection appears to be largely dependent on the accompanying dynamics. In the performing arts "projection" usually refers to the performers' dynamics which can make their performance so "big" so as to be felt all the way to the last row of the balcony. Preston-Dunlop (1981, p. 60) proposes that projection of spatial forms "is more than affected by timing and dynamics; it is, in many instances, created by them", that "Acceleration particularly ejects the choreutic line beyond the limits of the body", and that "forceful pressure into the space" also tends to elicit the perception of the spatial line extending outwards beyond the body.

These types of dynamic actions may be associated with the creation of spatial projectiles and so their paths beyond the body may be perceived by association with real-world experiences. For example a forceful throw or push of the arms, or a swing of the leg may elicit a perception of a spatial line being projected from the arm or leg, just as if an actual object had been thrown or kicked. This illusion might be increased if the performer's eyes follow that imagined line through the space.

APX. XV.22 Projection elicited from Bodily High-points.

In Rogers' (1969) discussion of sculpture he identifies a relationship with space of "extending into it" (p. 26) which create "focuses of thrust [which] may occur in the form of protuberances or bosses on the surface of a volume . . . gentle bulges or swellings . . . [or] definitely located protrusions". These high-points on the mass of a sculpture "have a strong directional quality . . . they point in a definite direction" (p. 42). He adds arrows to illustrations of sculptures as examples of how these high-points focus their thrust outwards, eliciting a perception of the sculpture projecting beyond its physical mass into the direction of the protrusion.

Preston-Dunlop (1981, p. 60) also identifies how the "nature of the body fragment" effects how readily a projection will be perceived from a particular body-part. Pointed angles and highlighted body-parts such as the eyes and hands tend to most easily be perceived as projecting a spatial form beyond themselves.

This perceived extension of a high-point beyond the body may also be an example of the Gestalt perceptual principal of "continuation" (see IVB.27) in which straight lines are perceived to continue their straight direction, and curved lines are perceived to continue their curvature, beyond the actual stimuli and into empty space.

APX. XV.23 Projection elicited from "Gamma movement".

A phenomenon of visual perception which may contribute to the perception of spatial projection was identified by Gestalt psychologists and termed "gamma movement" (Lindemann, 1922) in which the sides and corners of geometrical figures appear to expand outwards into space during brief visual exposures. Arnheim (1974, pp. 438–439) gives many examples of the gamma movement of polygons. The expanding-projecting motion varies with the shape and the orientation of the figure but in general it occurs along the figure's symmetry axes, what Arnheim calls the "structural skeleton of the pattern", and which he quotes Gestalt psychologist

E. B. Newman as referring to as the "'lines of force'". Arnheim describes the phenomenon:

> To the sensitive eye, even the simplest picture -- a dark spot on a light ground -- presents the spectacle of an object expanding from its center, pushing outward, and being checked by the counterforces of the environment. . . .
> . . . A traffic light flashing on at night seems to expand from its center toward the outside in all directions, similarly, its disappearance is seen as a centripetal shrinking toward the inside. (Arnheim, 1974, p. 438)

Gamma movement may be related to the symmetrical transformation of sizing (see IIID.20) which is probably the spatial transformation which is most easily and readily derived. The perception of a spatial form as outward beyond the body, larger than the body itself, may partly occur as a spontaneous enlargement transformation.

APPENDIX XVI

METHOD FOR DERIVING A TAXONOMY OF KINESPHERIC PATHS

A method is developed here for deriving a taxonomy of kinespheric pathways based on categories developed in choreutics and dance, anatomical constraints identified in kinesiology, and theories of motor control.

The initial taxonomy considers pathways of limb-motion created by concentric (shortening) muscular contractions. The taxonomy is based on the fundamental motion of the skeletal system which is angular movement. This is developed into more complex movements according to the three factors of single-joint versus multi-joint articulations; 2) single-phase versus multi-phase action; and 3) discrete versus gradual transitions between phases.

APX. XVI.10 Limits of the Taxonomy

APX. XVI.11 Self-motion and Limb-motion.

For simplicity this taxonomy is based on limb-motion rather than self-motion (see IIA.32). Self-motion is a wild-card, so to speak, in the path taxonomy developed here since the 'articulation' of the body with the floor does not follow the same characteristics as the articulations within the musculo-skeletal system (eg. there is no limit to the potential degree of rotation with the floor, whereas skeletal joints can only rotate to a certain degree). Indeed, some choreutic authors have advocated that self-motion be entirely ignored when determining the shape of a kinespheric path (Hardenbergh et al., 1990).

In normal human movement the limb-motions and self-motions blend seamlessly together so that any separation is artificial. This integration would also be true for an ideal form taxonomy. However, to simplify matters in this initial development limb-motion is considered alone.

APX. XVI.12 Types of Muscular Contraction.

Muscular contraction can be categorised into three types. In a shortening (concentric) contraction the muscle shortens and pulls the points of bony attachment closer together. In a lengthening (eccentric) contraction the muscle maintains tension but lengthens because of a voluntary gradual releasing of the tension, or if an external force overcomes the muscular force. In a static contraction (sometimes called isometric) the muscle develops tension but does not change length because of an external force or because of tension in other muscles (Rasch and Burke, 1978, p. 50;

Wells and Luttgens, 1976, p. 44). For simplicity, the taxonomy developed here will consider only shortening contractions.

APX. XVI.20 Taxonomic Attributes

APX. XVI.21 Skeletal System Produces Angular Motion.

Skeletal articulations at a single-joint always produce angular motion, that is, a curved line of the distal end of the body segment with the articulating joint at the centre of the curve. Rotation articulations are typically distinguished from angular articulations (eg. bending) but even rotary articulations (ie. the bone rotates around its own longitudinal axis) produce angular motion of any point that is not exactly on the rotational axis. This angular motion resulting from a rotatory articulation can be very large as in the case of forearm/hand motion produced by shoulder rotation when the elbow is flexed.

APX. XVI.22 Single-joint Versus Multi-joint Articulations.

The pathway of the distal end of a limb (eg. the hand) can be created by articulations in a single joint (eg. the shoulder), or in multiple joints (eg. vertebral joints, sternalclavicular joint, shoulder, elbow, wrist). Complexity increases as the number of articulating joints increases. These can generally be distinguished as single-joint versus multi-joint articulations.

APX. XVI.23 Single-phase versus Multi-phase Action.

The concept of a phase of muscular action is made explicit here. Each phase of action of a particular muscle group moves the body in a single direction which will necessarily end at the limit of the range of motion. The phase of action is the muscular counterpart to the spatial "stroke" identified in motor control.

Muscles are attached to bones by connective tissue (either a cord-like tendon or a flat sheet-like "aponeurosis") which extends beyond the muscle belly (containing the contractile fibres) and attaches to bone in one or more places which can be referred to as the points of bony attachment (Rasch and Burke, 1978, p. 34; Wells and Luttgens, 1976, p. 37). In a shortening (concentric) contraction the points of bony attachment on either end of the muscle will be pulled closer together along the shortest possible route. This can be referred to as the muscle's "line of pull" (Wells and Luttgens, 1976, pp. 38, 77) or the "line of application of the force" which is applied to the skeleton by a contracting muscle (Rasch and Burke, 1978. p. 117).

Most movements are created by groups of muscles rather than individual muscles and so the notion of "muscle groups" will be used here. Indeed, some muscles (eg. deltoid, pectoralis major) are not individual muscles at all but are composed of portions which can each contract independently and have different lines of pull (anterior, middle, and posterior deltoids; sternal and clavicular percoralis major) (Rasch and Burke, 1978, pp. 161-165; Wells and Luttigens, 1976, pp. 75-78). The notion of a muscle group will refer to the entire group of muscles which is contributing to a particular motion. It is understood that an individual muscle may be a member of more than one muscle group (eg. the middle deltoid is a member of the muscle group responsible for humerus horizontal extension, and a member of a different muscle group responsible for humerus abduction). A muscle group will also have a particular line of pull resulting from the simultaneous contribution of the lines of pull of all the individual muscles within the group. This is sometimes called a "synergy" in which individual muscles contribute their own individual lines of pull to produce a new, cooperative line of pull (Rasch and Burke, 1978, p. 47). For example the right or left external oblique abdominal muscles will rotate and laterally flex the spine if contracting alone but in cooperation they sagittally flex the spine.

Certain muscle groups have lines of pull which oppose the lines of pull of other muscle groups, that is, the shortening of certain muscles causes the lengthening of other muscles. These form reciprocal pairs of muscle groups which are referred to as "agonist" (shortening muscles) and "antagonist" (lengthening muscles). If the shortening/lengthening roles are reversed (ie. the movement goes in the opposite direction) then the roles of agonist/antagonist are also reversed. In this analysis the antagonist muscles are only implicitly stated. That is, when a muscle group is shortening, it is implied that the antagonist muscles are lengthening, and vice versa.

The amount of muscular shortening and skeletal motion are limited by several factors which include; the muscle's shortest possible state; the longest possible state of the antagonist muscles and ligaments around the articulating joint; bony stops (eg. elbow or knee extension), and the bulk of muscle and fat tissue (eg. elbow or knee flexion). Once a limit of motion has been reached the only way for motion to continue is for a different muscle group to contract, thus changing the direction of motion.

The mass-spring model of motor control posits that the elemental unit of body-movement consists of a single motion toward a new "equilibrium point" where there is equal tension between agonist and antagonist muscles (Bizzi and Mussa-Ivaldi, 1989; Jordan and Rosenbaum, 1989; see IIIB.20). In related studies of "trajectory formation" (ie. how the motor system produces complex pathways) measurements of the degree of path curvature and the velocity along the path both revealed that a path was divided into several "path segments" separated by "curvature peaks" (Abend et al., 1982; Morasso, 1983b; see IIIB.30). A model for the production of complex paths was developed in which the path segments are referred to as "strokes" which are "abstract representations" of kinespheric information (Morasso et al., 1983, p. 97) and so appear to be the "primitive movements in the motor repertoire" (Morasso, 1986, p. 44). Laban (1966, pp. 27-28) also identified these same attributes and referred to them as "'peaks' within the trace-form" and "phases of its pathway" (see IIIB.40).

The notion of a "phase" of action will be used here, as the muscular counterpart to a spatial "stroke", to indicate that one muscle group is shortening (also implying that the antagonists are lengthening). When a new muscle group begins to shorten this will be referred to as a new phase and will produce a new stroke. Since each muscle group has a different line of pull, each phase will produce a stroke moving in a different direction (even if only slightly).

This notion of "phases" of an action has been used in kinesiology (Rasch and Burke, 1978, p. 50; Wells and Luttigens, 1976, p. 45), motor control studies (Tuller et al., 1982, pp. 259-260), and in choreutics (Bartenieff and Lewis, 1980, pp. 73-78; Laban, 1966, pp. 27-28) to refer to the different component sub-movements or individual contractions of muscle groups within a larger movement phrase. The term "phasing" is also used to refer to the relative timing among the components within a movement sequence (Shapiro and Schmidt, 1982, p. 136; Wing, 1980).

A single phase is a single contraction of a muscle group which moves the skeleton along a single line of pull and exhibits a single spatial stroke. According to the mass-spring model of motor control, agonist/antagonist equilibrium positions serve as guiding points. Assuming the movement continues, at each guiding point a curvature peak will be exhibited during the transition from one phase to the next. The next phase necessarily consists of a different muscle-group (even if only slightly) which moves the skeleton along a new line of pull.

APX. XVI.24 Phase Transitions: Discrete (Angular) Versus Gradual (Curved).

The traditional view in dance and choreutics often draws an initial distinction between straight versus curved paths, and then posits that angles are composed of a series of straight paths while rounds, loops, figure-8s, etc. are composed of a series of curved paths (eg. Preston-Dunlop, 1980, pp. 87-88; 1981, p. 44; Hutchinson-Guest, 1983, p. 167). This view is not adopted here for two principal reasons. Curved paths are the fundamental motion produced by skeletal articulations, straight paths are comprised of two or more simultaneous component curved paths and so must be considered to be kinesiologically more complex. Also, straight paths are not necessary to produce angles since an angle may occur at an abrupt transition between two curved paths.

The conception of motor control developed by Morasso and Colleagues (Morasso, 1986; Morasso et al., 1983) will be followed here. This model posits that the motor system executes a spatial trajectory by producing a series of "path segments" or "strokes". Angular transitions between strokes occur when they are performed in a discontinuous manner, whereas a partial time overlap between consecutive strokes causes one stroke to be blended into the next creating a smoothly curving transition. That is, one stroke begins before the previous stroke has ended and so the two strokes are momentarily superimposed. This model of "trajectory formation" is identified as being similar to "spline functions" which generate curved lines from a series of straight vectors in computer graphics (eg. Morasso, 1986, pp. 38-42) such that "the desired shape is approximated by means of a polygon" and then "the sides of the polygon are generated and superimposed" (Morasso et al., 1983, p. 86). The amount which two consecutive polygon edges are overlapped (ie. "superimposed") determines the degree of curvature between successive strokes.

According to this model an "S"-shaped and a "Z"-shaped wave are classified into the same category, the only difference being the type of transition between strokes. This conception appears to have been implicitly followed by Laban (1966) when he classified a "2"-shaped path (which includes an angle) as being an "S"-shaped wave (pp. 83-84). Laban also asserted that "to perform angular sections, we must give each section a special accentuation" (p. 46), and thus a "cone-shaped trace-form" can be "executed smoothly in a continuously curving pattern" or the "same trace-form" can be "executed in a broken or angular way, with almost imperceptible pauses between each section" (p. 47). And in another place Laban (1963, pp. 93-94) describes that "movements . . . can be performed either fluently or angularly. In fluent performance more stress will normally be laid on the paths, and in angular performance on the points".

The fluent, overlapping, transitions creating curved transitions between strokes will be referred to here as "gradual" phase transitions. The broken, abrupt transitions creating angles between strokes will be referred to here as "discrete" phase transitions.

APX. XVI.30 Initial Taxonomy

An initial taxonomy of kinespheric paths is developed here based on single-phase versus multi-phase actions and single-joint versus multi-joint articulations. The taxonomy presented here is by no means complete. This is merely an example of how categories of pathways can be distinguished using these kinesiological and motor control attributes.

Tables are used to represent many of the paths (see below). These are analogous to the representations used for the relative timing of four motors in Vredenbregt and Koster's (1971) mechanical handwriting simulator (see IIIB.50), with Wing's (1978, p. 168) table of the EMG activity in four muscles used in writing, and also with Glencross' (1975, p. 24) representation of the major arm muscles during a circular path of the hand. In all cases the path is represented in discrete phase transitions but gradual transitions can also be derived by overlapping any phase of action into an adjacent "empty" phase indicated by an asterisk (*) in the table.

APX. XVI.31 Single-phase Paths.

APX. XVI.31a Arc.

The simplest movement is a single-phase action at a single joint which will create a curved arc-shaped path of any point of the moving limb (except the point at the centre of rotation). The arc is the fundamental path of which all other paths are composed. This is similar to Winearls' (1958) "half-circle" (except that the half-circle was limited to elbow and knee joints), appears to be identical to Lomax and colleagues' (1968) "use of planes-arc", and is one example of Dell's (1970) "arc-like directional" (planar-curl is another example; see below). This single-phase path can never be a complete cycle since the direction of the line of pull of the agonist muscle-group will eventually reach its limit of motion.

In geometric terminology an "arc" refers to a portion of the circumference of a circle (Rich, 1963, p. 3). The concept of a "planar arc" is redundant since an arc is planar by definition. In general terms a single-phase single-joint motion will produce a perfect arc, though at a precise level of detail this will not be true since the exact centre of rotation in skeletal joints will change (as much as one-half inch in the elbow and three-quarters inch in the shoulder) (Dempster, 1955, pp. 570-573).

APX. XVI.31b Planar-curl

When multi-joints of a single-phase action articulate in corresponding (ie. the same) directions, the curve will remain within a single plane and the distal-end of the limb will progressively either decrease or increase its diameter of curvature. The pathway will be in the shape of a spiral but this term is usually associated with multi-phase plastic paths and so is not used here. The term "curling" was suggested in Hutchinson's (1970, p. 319) discussion of multi-jointed "bending" movement.

At a fine level of detail a pure planar path of a multi-joint articulation may be impossible since the skeletal links do not articulate exactly within the same plane (Dempster, 1955, p. 570; see IVA.70), however a single plane may be closely approximated. Planar-curls are typical for actions of muscles which span two joints (eg. hamstrings, rectus femoris, biceps brachii) and so apply the same line-of-pull to two body-segments.

APX. XVI.32c Plastic-curl.

When multi-joints of a single-phase action articulate in intersecting planes the resulting path of the distal end of the limb cannot be contained within a single plane and so might be termed a "plastic curl". For example, this might occur when rotating the shoulder joint while simultaneously bending the elbow. Hutchinson (1970, pp. 311-313) refers to this as a "combined twist and tilt" or a "skew curve".

APX. XVI.33d Radius / Transverse-segment.

When multi-joints in a single-phase action articulate in contrary (ie. opposite) directions a nearly straight path of the distal-end will be produced. A pure straight path requires precise coordination within the limb, in practice the path is likely to deviate slightly. This path can be referred to as a "radius" (directly towards or away from centre) or as a "transverse-segment" (not towards or away from centre) (see "transversal" below). This single-phase action cannot move further than half-way across the kinesphere since further motion would require one of the articulations to reverse its direction (ie. a second phase of action).

APX. XVI.34 Two-Phasic Actions.

A second phase of action by a different muscle group will create changes in the direction of the trajectory. The new phase can act on the same joint or on a different joint than the first phase.

APX. XVI.34a Reversal.

When the agonist and antagonist muscle groups of phase-1 totally reverse their roles in phase-2, then the path will retrace itself in the opposite direction. This can occur in single-joint or multi-joint articulations. The phase-transition is necessarily discrete since muscles cannot act as agonist and antagonist at the same time (which would be necessary to overlap the two phases of a reversal). This two-phasic pattern (applicable to any muscle-group) is represented in Table A. Phase-1 and phase-2 of the reversal will both be the same type of single-phase motion (two arcs, two curls, two chord-segments).

Table A. Reversal.

	phase 1	phase 2
Muscle-group #1:	shorten	lengthen

APX. XVI.34b Direction-change.

If the two-phases are not reversals then a direction-change occurs between phase-1 and phase-2. A discrete transition between phases will create an angular direction-change and a gradual transition will create a curving direction-change.

Paths created by muscles acting on the shoulder and the elbow can be taken as examples. One muscle-group may shorten during phase-1 while another muscle-group shortens during phase-2 (Table B), or one muscle-group might reverse its articulation from phase-1 to phase-2 (Table C).

Table B. Direction-change (discrete transitions).

	phase 1	phase 2
Muscles#1 (elbow):	flex	*
Muscles#2 (shoulder):	*	in-rotate

Table C. Direction-change with a reversal (discrete transitions).

	/ phase 1 /	phase 2 /
Muscles#1 (elbow):	flex /	extend /
Muscles#2 (shoulder):	* /	in-rotate /

APX. XVI.34c Diameter / Transversal.

A 180° direction-change between two single-phase radii or transverse-segments will create a linear path which can be referred to as a "diameter" (passing through centre) or a "transversal" (not passing through centre). In geometric terminology these can both be referred to as "chords" (a diameter is a chord passing through centre) but "chord" is also used in choreutics in the musical sense to describe simultaneous directions in a kinespheric pose (see IVB.25) and so to avoid confusion it is not used here. The term "transversal" is adopted here since it is used in choreutics (Laban, 1966, p. 68) and also in geometry to refer to a line which "cuts across" other lines (eg. Rich, 1963, p. 36).

APX. XVI.35 Three(or more)-phasic Actions.

APX. XVI.35a Cycle.

A path which ends at the same place it began it can be referred to as a "cycle". When the cycle is large, close to a complete circumference of the kinesphere it might be referred to as a "great cycle" and when it is small it might be called a "small cycle". These terms are analogous to the geometric "great circle" (any circumference of a sphere) and "small circle" (any circle on the surface of a sphere other than the great circles) (eg. Rich, 1963, p. 206).

Cycles can be produced in three, four, or more phases. If the phase-transitions are overlapping then a rounded cycle will occur. If the transitions are discrete then a triangle, quadrangle, etc. will occur. The same examples as in Table B and Table C (see above) can be used here to demonstrate how a three-phase cycle is essentially identical to a two-phase direction-change with phase-3 to complete the cycle (Table D) or the cycle can occur in four phases (Table E). More phases could be added to create more (and subtler) changes of direction within the cycle.

Table D. Three-phasic cycle (discrete transitions).

	phase 1	phase 2	phase 3
Muscles#1 (elbow):	flex	*	extend
Muscles#2 (shoulder):	*	in-rotate	out-rotate

Table E. Four-phasic cycle (discrete transitions).

	phase 1	phase 2	phase 3	phase 4
Muscles#1 (elbow):	flex	*	extend	*
Muscles#2 (shoulder):	*	in-rotate	*	out-rotate

APX. XVI.35b Single-joint cycle (circumduction).

A single-joint cycle is referred to in kinesiology as circumduction. When rotation is also available in the single-joint (eg. hips, shoulders) then a hidden rotation will occur during the circumduction cycle. This automatic rotation during arm circumductions is sometimes known as "Codman's paradox" in which "during successive movement about two of the axes of the shoulder [eg. flexion and adduction] movement also occurs mechanically about the third axis [ie. rotation]" (Kapandji, 1970, p. 20). This hidden rotation is often unnoticed by the performer but it is revealed by the direction which the palm is facing (for shoulder circumductions) (Hutchinson-Guest, 1983, pp. 204-205). The rotation might occur all at once, or it may occur evenly throughout the cycle. An example for hip circumduction in given in Table F.

Table F. Hip circumduction (discrete transitions).

	phase 1	phase 2	phase 3	phase 4
Muscles#1 (hip):	flex	*	extend	*
Muscles#2 (hip):	*	abduct	*	adduct
Muscles#3 (hip):	*	outward rotation	*	*

APX. XVI.35c Spiral (modified cycles).

A series of cycles can be modified to create a spiral. If the central pivot point of the cycles does not change then a spiral can be created by gradually decreasing or increasing the size of the articulations during each successive cycle. Because the motion of the body-segment creates a cone, this might be termed a conic-spiral.

The central pivot point of the cycles might also be shifted through space by a third-muscle group thus creating a type of helix-spiral. An example for an elbow-centred spiral is given in Table G. If the spiral occurs at a global joint then hidden rotation will also occur. An example for a shoulder-centred spiral is given in Table H (the extended arm moves in circles around the sagittal forward direction).

Table G. One cycle of Elbow-centred spiral (discrete transitions):

	phase 1	phase 2	phase 3	phase 4
Muscles#1 (elbow):	flex	*	extend	*
Muscles#2 (shoulder):	*	in-rotate	*	out-rotate
Muscles#3 (shoulder):	*	horizontal flexion		*

Table H. One cycle of shoulder-centred spiral (discrete transitions):

	phase 1	phase 2	phase 3	phase 4
Muscle#1 (shoulder):	horz-flex	*	horz-extend	*
Muscle#2 (shoulder):	*	flex	*	extend
Muscle#2 (shoulder):	*	- - - outward rotate - - -		*
Muscle#3 (torso):	*	- - - - flex - - - - - -		*

APX. XVI.35d Wave.

A wave can be produced in three phases. One possibility is two reversals of one muscle-group shifted through space by a second muscle-group (Table I). A variation of this wave can occur if the elbow flexion occurs in fractions (Table J). Discrete transitions will create a "Z"-shaped path and gradual transitions will create an "S"-shaped path.

Table I. Elbow and shoulder wave (discrete transitions):

	phase 1	phase 2	phase 3
Muscles#1 (elbow):	flex	extend	flex
Muscle#2 (shoulder):	*	- - in-rotate - -	

Table J. Elbow and shoulder wave variation (discrete transitions):

	phase 1	phase 2	phase 3
Muscles#1 (elbow):	1/2 flex	*	1/2 flex
Muscle#2 (shoulder):	*	in-rotate	*

APX. XVI.35e Spiral/wave.

Any plastic spiral or wave (ie. not entirely within a plane) will exhibit both spiral-like and a wave-like attributes. Which of these is most obvious will depend on the observer's viewpoint. The spirals already discussed (Tables G, H, above) also exhibit wave-like attributes but will be kinesthetically experienced as more cyclical or spiral-like since they have a continual direction of joint rotation. Spiral/waves which contain a reversal of joint rotation (or pronate/supinate "rotations" of the forearm about its longitudinal axis) may be kinesthetically experienced as more wave-like. These can occur entirely within a single joint (Table K, phases 2-4) or within multi-joints (Table L).

Table K. Hip wave with rotation reversal (phases 2-4):

	phase 1	phase 2	phase 3	phase 4
Muscles#1 (hip):	extend	*	flex	*
Muscles#2 (hip):	*	abduct	adduct	abduct
Muscles#3 (hip):	*	out-rotate	in-rotate	out-rotate

Table L. Multi-joint wave with "rotary" pronate/supinate reversal.

	phase 1	phase 2	phase 3
Muscles#1 (shoulder):	*	in-rotate	*
Muscles#2 (elbow):	flex	extend	flex
Muscles#3 (forearm):	supinate	pronate	supinate

APX. XVI.35f Reversing-cycle Figure-8s.

One way to conceive of a figure-8 shaped path is as a fourth phase which joins the ends of a three-phase wave. One muscle-group will reverse its action every phase, while another reverses its action every other phase. If phase-transitions are gradual, then a smooth figure-8 will occur, if transitions are discrete then an angular form will occur. Alternatively, a figure-8 can be conceived as two cycles which each turn in opposite directions. The wave-forms in Table K and Table L (see above) can be extended into figure-8s in Table M and Table N respectively. The cyclic components can be identified by the phases of rotary articulation.

Table M. Hip figure-8 with rotation reversal:

	phase 1	phase 2	phase 3	phase 4
Muscles#1 (hip):	*	extend	*	flex
Muscles#2 (hip):	abduct	adduct	abduct	adduct
Muscles#3 (hip):	- - out-rotate - -		- - - in-rotate - - -	

Table N. Multi-joint figure-8 with "rotary" pronate/supinate.

	phase 1	phase 2	phase 3	phase 4
Muscles#1 (shoulder):	*	in-rotate - - -	*	out-rotate - - -
Muscles#2 (elbow):	flex	extend	flex	extend
Muscles#3 (forearm):	- - - pronate - - -		- - - supinate - - -	

Because of the articulations possible in the forearm and wrist they can produce a figure-8 with a different phasic pattern, one which is identical to the pattern usually producing cycles (Table O).

Table O. Wrist-forearm figure-8:

	phase 1	phase 2	phase 3	phase 4
Muscle#1 (wrist):	flex	*	extend	*
Muscles#2 (forearm):	*	supinate	*	pronate

APX. XVI.35g Continual-cycle Figure-8s.

The figure-8s presented so far are characterised by a reversal in the direction of cycling, probably accompanied by a rotary articulation reversal. A fundamentally different type of figure-8 maintains a continuous direction of cycling and so may be kinesthetically perceived as more spiral-like. This continual-cycle figure-8 can only be produced in multi-joints by connecting the end of a helix-spiral back to its beginning. For example, the shoulder-centred spiral presented in Table H (see above) can be continued so that in phases 5-8 it returns to its beginning point and creates a figure-8 shaped path (Table P) (the arm circles around the sagittal forward direction).

Table P. Eight-phase continual-cycle figure-8:

	phase 1	phase 2	phase 3	phase 4
Muscles#1 (shoulder):	horz-flex	*	horz-extend	*
Muscles#2 (shoulder):	*	flex	*	extend
Muscles#3 (shoulder):	*	- - - outward rotate - - -		*
Muscles#4 (torso):	*	- - - - flex - - - - - -		*
	phase 5	**phase 6**	**phase 7**	**phase 8**
Muscles#1 (shoulder):	horz-flex	*	horz-extend	*
Muscles#2 (shoulder):	*	flex	*	extend
Muscles#3 (shoulder):	*	- - - outward rotate - - -		*
Muscles#4 (torso):	*	- - - -extend- - - - - -		*

Phases 1-4 are identical to phases 5-8 except that one muscle-group has reversed its action, thus transporting the spiral in the opposite direction. Individual phases may merge into 2-part single-phases which have the rhythm of "and-one", "and-two" etc. Thus, the eight-phasic pattern might be abbreviated into four phases (Table Q).

Table Q. : Continual-cycle figure-8 merged into four phases:

	/ phase and-1	/ phase and-2	/ phase and-3	/ phase and-4 /
#1 (shoulder):	horz-flex	/horz-extend	/horz-flex	/horz-extend /
#2 (shoulder):	-flex/	-extend/	-flex/	-extend/
#3 (shoulder):	- - - - - - outward rotate - - - - - -			/
#4 (torso):	- - flex - -	/	- - extend - -	/

APX. XVI.40 Conclusions: Taxonomy of Kinespheric Paths

The four taxonomic attributes: 1) The fundamental curved movement; 2) Single-joint versus multi-joint articulations; 3) Single-phase versus multi phase actions, and; 4) Discrete or gradual phase transitions; can be used to develop a taxonomy of kinespheric paths. An initial exploratory taxonomy has been developed here. Further refinements to this type of taxonomy based on characteristics of anatomy and motor control can lead to a kinesiologically valid categorisation scheme. This is a matter for future research.

APX.XVII.10 Written Instructions Given to Subjects

MOVEMENT MEMORY EXPERIMENT

Thank you for participating in this experiment which is designed to study memory for body-movements. I am conducting this experiment as a part of a research degree at the Laban Centre.

In this experiment you will be asked to recall body-movements. Your performance of these movements will be video-taped so that I can observe them later. During the actual video-taping I will be out of the room and will not be watching you while you move.

I cannot provide you with full details about the theory behind this experiment at this time since this might bias your responses. Full details about the theory and the results of this experiment can be available from me at the conclusion of this research. However I do guarantee that:

1) This research does not include any assessment of your personal movement skill.

2) The video-tape recording of your movements will not be seen by anyone except myself and possibly by my research tutors Dr. Valerie Preston-Dunlop (Laban Centre) and Dr. Linda Pring (Goldsmiths' College).

3) Your name will not appear in any written or verbal discussion of this experiment.

Just relax and do your best. I will have a little treat as a reward for you when you finish.

Jeffrey

MOVEMENT MEMORY EXPERIMENT

OVERALL TASK:

You will be requested to learn 16 different body-movements.

Procedure:

1) LEARNING: The movements will be shown to you on video-tape.

2) Each movement will be demonstrated three times in a row. Please physically perform the movements along with the video-tape. By the third demonstration of the movement, try to do it for yourself without relying on observing the video.

3) After each movement is demonstrated three times, a grid-pattern will appear briefly on the video to indicate that the next movement is about to be shown.

4) The entire video-tape, with each movement demonstrated three times, lasts approximately 5.5 minutes. No one will be watching you while you learn these movements and you will not be video-taped. At the end of the video the grid-pattern will appear several times on the screen alternating with blackness. This indicates that the video is over. Pleas knock on the door at this time and tell me that the video is over.

5) RECALL: You will then be asked to recall as many of the movements as you can remember. You will be video-taped while you do this but no one will be in the room watching you.

6) Please DO NOT make a continuous sequence by joining all the movements together. Start each movement from a neutral position and keep each movement separate from every other movement. In order to help me determine where one movement stops and the next one begins, please say out loud"HERE'S ONE" (or anything like that) just before you demonstrate each movement.

7) You can recall the movements in any order in which you remember them. Try to recall each movement only once, as quickly as possible, and as accurately as possible.

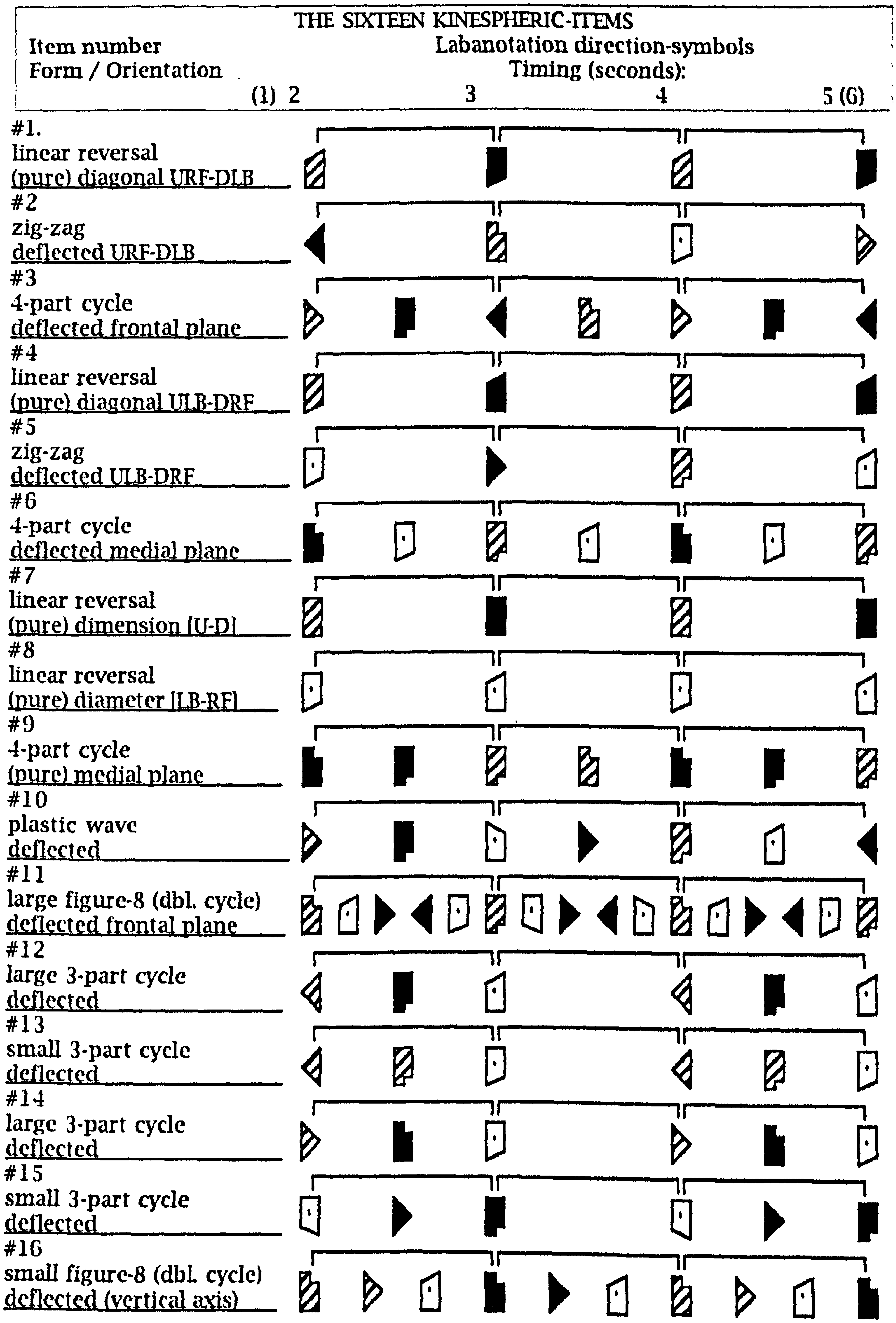
8) You will be given 4 minutes to recall the movements. After this time I will come into the room and tell you to stop. If you finish before this time, or can't remember any more movements, then open the door and tell me that you have stopped.

9) REPEAT: This whole process, steps 1-8, will occur five times so that you will have five chances to successfully remember all of the movements.

10) On each of the five learning periods, the video-tape will show the same set of movements in a different order. Simply keep rehearsing the movements and recall them in whatever order that you remember them.

Before the experiment starts I will show you three practice movements so you can have an example of what will happen. I will watch you rehearse these three practice movements along with the video-tape, and then recall them, to make sure that you understand the instructions explained above. After this you can forget the practice movements since they play no further part in the experiment.

#1. linear reversal;	(pure) [ ] diagonal.
#2. zig-zag;	deflections of [ ] diagonal.
#3. 4-part cycle;	deflected frontal plane and [ ] diagonal.
#4. linear reversal;	(pure) [ ] diagonal.
#5. zig-zag;	deflections of [ ] diagonal.
#6. 4-part cycle;	deflected medial plane and [ ] diagonal.
#7. linear reversal;	(pure) [ ] dimension.
#8. linear reversal;	(pure) [ ] diameter.
#9. 4-part cycle;	(pure) medial plane.
#10. plastic wave;	3 deflected diagonals orbiting the [ ] axis.
#11. Large figure-8;	deflected frontal planes orbiting the [ ] axis.
#12. large 3-part cycle;	3 deflected diagonals orbiting the [ ] axis.
#13. small 3-part cycle;	3 deflected diagonals orbiting the [ ] axis.
#14. large 3-part cycle;	3 deflected diagonals orbiting the [ ] axis.
#15. small 3-part cycle;	3 deflected diagonals orbiting the [ ] axis.
#16. small figure-8;	deflected horizontal planes orbiting [ ] axis.


THE SIXTEEN KINESPHERIC-ITEMS
Item number
Form / Orientation
Labanotation direction-symbols
Timing (seconds):
(1) 2
3
4
5 (6)
#1.
linear reversal
(pure) diagonal URF-DLB
#2
zig-zag
deflected URF-DLB
#3
4-part cycle
deflected frontal plane
#4
linear reversal
(pure) diagonal ULB-DRF
#5
zig-zag
deflected ULB-DRF
#6
4-part cycle
deflected medial plane
#7
linear reversal
(pure) dimension [U-D]
#8
linear reversal
(pure) diameter [LB-RF]
#9
4-part cycle
(pure) medial plane
#10
plastic wave
deflected
#11
large figure-8 (dbl. cycle)
deflected frontal plane
#12
large 3-part cycle
deflected
#13
small 3-part cycle
deflected
#14
large 3-part cycle
deflected
#15
small 3-part cycle
deflected
#16
small figure-8 (dbl. cycle)
deflected (vertical axis)

APX. XVII.30 Order of the Kinespheric-Items within the Five Learning Sequences

Position in the Sequence	Learning Sequences A	B	C	D	E
1]	2	5	14	8	3
2]	6	12	7	3	13
3]	15	14	4	9	2
4]	14	1	12	10	12
5]	8	7	13	1	11
6]	11	3	10	5	16
7]	1	2	3	15	14
8]	12	10	5	7	9
9]	9	16	6	11	7
10]	5	4	8	14	10
11]	13	6	2	2	15
12]	7	11	9	4	4
13]	16	13	16	13	5
14]	3	8	1	6	8
15]	4	15	15	12	1
16]	10	9	11	16	6

FIVE PRESENTATION ORDERS OF THE LEARNING SEQUENCES:

		Subjects:
Order #1	A-B-C-D-E	A, F, K
Order #2	B-E-D-C-A	B, G, L
Order #3	C-D-E-A-B	C, H
Order #4	D-A-B-E-C	D, I
Order #5	E-C-A-B-D	E, J

APX. XVII.40 Analyses of Data

APX. XVII.41 Abbreviations in the Analyses of Data.

* Refers to an unrecognizable recall within subjects' recall orders.

x Refers to an apparent variation of one of the kinespheric items, (eg. 4x) these were not counted as created S-units.

#Os Refers to the number of occurrences that an S-unit is recalled.

#ITRs Refers to the number of intertrial repetitions that occurred for a particular S-unit.

S-units are abbreviated by the numbers of the two component kinespheric-items (eg. 6/9). For easy indexing the lower number is always listed first but it is understood that either item might be recalled first.

Specific occurrences of S-units are abbreviated by a letter representing each subject followed by the number of the recall trial (eg. B4 refers to the 4th recall trial of subject B, etc.)

APX. XVII.42 Order of Subjects' Responses.

Subject:

Recall:	Order of Responses:
first	7 1 10 * 13
second	7 1 14 * 11 9 13 15 10
third	* * 1 14 * 11 9 13 15 10
fourth	4 1 * 7 13 15 9 * 11 * 8 *
fifth	1 * 7 9 13 15 * 8 * 16 11 8 * * 9

Subject: B

Recall:	Order of Responses:
first	9 6 13 11 5
second	6 9 3 5 8 11 13 7 4
third	10 11 6 9 7 13 8 5 2 15 3 14
fourth	9 6 13 15 5 2 11 10 1 3 14 8 4
fifth	3 10 14 4 8 7 9 6 12 16 15 5 2 11

Subject: C

Recall:	Order of Responses:
first	2 15 9 11
second	9 13 14 11
third	2 15 14 9 7 10 11 13
fourth	13 10 9 15 2 13 10 1
fifth	8 9 7 14 11 2 13 10 1

Subject: D

Recall:	Order of Responses:
first	3 6 13 8
second	7 5 13 3 6 2 15 9
third	15 9 11 5 2 13 8 10 3
fourth	9 11 6 7 12 13 2 5 8 3 4 15
fifth	10 2 5 6 11 9 16 8 3 15 7 13 12

Subject: E

Recall:	Order of Responses:
first	1 15 6 4 * * 14 13 7
second	11 14 9 6 5 13 7 12 2 *
third	13 15 9 6 8 4 2 5 3 11 14 7 *
fourth	13 15 9 6 10 8 4 2 5 14 3 11 7
fifth	14 3 11 16 8 4 5 2 6 9 10 15 13 7

Subject: F

Recall:	Order of Responses:
first	(nothing recalled)
second	5 9 8 14
third	1 3 14 10
fourth	8 9 6 1 10 3 13 5 11
fifth	7 9 6 1 3 14 10 14 5

Subject: G

Recall:	Order of Responses:
first	* 14 9 * 11 * * 2x 7
second	7 14 6 3 * 1 2 15 13 4 2x
third	7 14 9 6 12 5 2 13 8 3 16
fourth	14 7 8 13 * 2x 6 9 2 1 16 5 *
fifth	7 9 * 4 13 16 5 15 2x 14 8 * 3 * *

Subject: H

Recall:	Order of Responses:
first	8 7 9 11 14
second	8 9 14 3 5 7 11 15 13
third	8 7 11 5 14 3 6 13 14x 15 3
fourth	8 5 13 15 14 9 6 7 10 4 3 14x
fifth	8 5 7 15 14 11 9 13 4 12 16 3 14x 4 2

Subject: I

Recall:	Order of Responses:
first	3 9 8 * 6
second	7 4 6 8 15 1 9 2 13 16
third	7 15 14 9 6 12 11 8 4 2 1 3
fourth	8 7 13 16 6 4 5 14 2 11 15 3 1 * 10
fifth	7 1 8 4 9 6 11 15 12 2 5 14 3 16 * 13

Subject: J

Recall:	Order of Responses:
first	1 6 8
second	1 9
third	7 1 9 2 13
fourth	7 9 13 1 * 6
fifth	7 13 2 8 1 5 9 10

Subject: K

Recall:	Order of Responses:
first	5 7 16 4 * 1 10 * 8
second	7 8x 8 13 9 1 11 * 9x 15 * *
third	14 7 8 11 5 13 16 1 15 * 5 10 8x * 9 9x 3 *
fourth	14 4 7 15 8 6 11 9 13 3 * 4x * 10 *
fifth	14 7 15 9 1 2 3 10 6 4x 13 4 * 9x11 *

Subject: L

Recall:	Order of Responses:
first	9 8 15 5 1
second	9 8 6 15 5 3 * 7 13
third	8 9 6 3 7 13 5 11 15 12 1
fourth	11 1 7 8 10 9 6 16 13 12 14 5 4 3 15
fifth	9 6 8 3 15 10 4 16 13 14 5 7 1 12

APX. XVII.43 Performance Measures.

Number of Correctly Recalled Kinesthetic-items:

Subjects:

Recall trials	A	B	C	D	E	F	G	H	I	J	K	L	Mean Recalls	S.D.
1st	4	5	4	4	7	0	5	5	4	3	7	5	4.42	1.83
2nd	7	9	4	8	9	4	10	9	10	2	9	8	7.42	2.64
3rd	8	12	8	9	12	4	11	11	12	5	15	11	9.83	3.16
4th	8	13	8	12	13	9	11	12	14	5	12	15	11.00	2.92
5th	10	14	9	13	14	9	11	15	15	8	14	14	12.17	2.59

Observed Intertrial Repetitions [O(ITR)s]:

Subjects:

Recall trials	A	B	C	D	E	F	G	H	I	J	K	L	Mean O(ITR)s	S.D.
1st-2nd	1	2	0	1	1	0	0	0	0	0	0	2	0.58	0.79
2nd-3rd	1	3	0	1	2	0	1	2	0	1	0	2	1.08	1.00
3rd-4th	1	3	1	3	7	0	3	0	1	0	0	1	1.67	2.06
4th-5th	1	5	1	5	6	2	0	3	2	0	1	5	2.58	2.15

Expected Intertrial Repetitions [E(ITR)s]:

Subjects:

Recall trials	A	B	C	D	E	F	G	H	I	J	K	L	Mean E(ITR	S.D.
1st-2nd	0.14	0.89	0.25	0.38	0.38	0.00	0.24	0.89	0.10	0.00	0.06	0.60	0.33	0.32
2nd-3rd	1.07	1.04	0.75	0.83	0.78	0.00	0.55	1.13	0.93	0.40	0.83	1.27	0.80	0.35
3rd-4th	0.94	1.41	0.94	1.04	1.69	0.33	1.16	1.36	1.07	0.96	0.88	1.33	1.09	0.35
4th-5th	1.40	1.21	1.17	1.15	1.71	0.74	0.93	1.00	1.26	0.60	1.07	1.73	1.16	0.34

Pair Frequency (PF):

Subjects:

Recall trials	A	B	C	D	E	F
1st-2nd	0.86	1.11	-0.25	0.63	0.62	0.00
2nd-3rd	-0.07	1.96	-0.75	0.17	1.22	0.00
3rd-4th	0.06	1.59	0.06	1.96	5.31	-0.33
4th-5th	-0.40	3.79	-0.17	3.85	4.29	1.26

Recall trials	G	H	I	J	K	L	Mean PF	S.D.
1st-2nd	-0.24	-0.89	-0.10	0.00	-0.06	1.40	0.26	0.66
2nd-3rd	0.45	0.87	-0.93	0.60	-0.83	0.73	0.285	0.87
3rd-4th	1.81	-1.36	-0.87	-0.96	-0.80	-0.33	0.58	1.85
4th-5th	-0.93	2.00	0.74	-0.60	-0.87	3.27	1.42	1.95

APX. XVII.50 Survey of Subjective-Units (S-units)

S-unit	#Os	#ITRs	Specific Occurrences
1/3	2	1	I3-I4
1/6	2	1	F4-F5
1/7	4	2	A1-A2 L4-L5
1/9	2	1	J2-J3
2/4	2	1	E3-E4
2/5	9	6	B3-B4-B5 D3-D4-D5 E3-E4-E5
2/11	2	1	B4-B5
2/13	2	1	D3-D4
2/15	2	1	C3-C4
3/6	2	1	D1-D2
3/8	2	1	D4-D5
3/11	3	2	E3-E4-E5
3/14	4	2	E4-E5 H2-H3
3/15	2	1	L4-L5
4/8	5	3	B4-B5 E3-E4-E5
5/8	4	2	B2-B3 H4-H5
5/14	4	2	I4-I5 L4-L5
5/15	4	2	B4-B5 L1-L2
6/9	16	11	B1-B2-B3-B4-B5 E2-E3-E4-E5 F4-F5 G3-G4 L3-L4-L5
6/11	2	1	D4-D5
7/11	2	1	H2-H3
7/13	6	3	B2-B3 E1-E2 L2-L3
7/14	3	2	G2-G3-G4
7/15	2	1	K4-K5
8/9	3	2	L1-L2-L3
8/13	2	1	G3-G4
9/11	5	3	A2-A3 D3-D4-D5
9/15	4	2	D2-D3 E3-E4
10/11	2	1	B3-B4
10/13	2	1	C4-C5
11/13	2	1	B1-B2
11/14	2	1	E2-E3
11/15	2	1	I4-I5
12/13	2	1	D4-D5
13/15	6	4	A3-A4-A5 E3-E4-E5
13/16	2	1	L4-L5
14/15	2	1	H4-H5

ABBREVIATIONS: See APX. XVII.41 above.

APX. XVII.60 Form and Orientation Within the Twelve Strongest S-Units

(For data, see next page)

For each of the twelve strongest S-units it was asked:

1) Do the two items within the S-unit exhibit the same form?

2) Do the two items within the S-unit exhibit the same orientation?

The determination for each S-unit was then multiplied by the number of ITRs of than S-unit in order to answer the questions:

1) Do the items within each S-unit ITR exhibit the same form?

2) Do the items within each S-unit ITR exhibit the same orientation?

In some instances $^1/_2$ credit was given when some form attributes were the same but others were different.

Whether the two movement items had the same orientation was difficult to quantify and was therefore necessarily bias by a certain amount of interpretation. Some movements contained paths with several different orientations. The two items in an S-unit might have a partially similar and a partially different orientation. When orientations were partially the same $^1/_3$ credit was given for each dimensional component which was shared between the two kinespheric-items.

Certain items had been put in the stimulus list which had the exact same orientation (eg. #1, #2, #3) but these were not organised into any S-units. The difficulty in quantifying the degree of similar orientation attests to the need for a more tightly controlled selection of items so that the orientation similarity between every possible pairing of items within the stimulus list is predetermined (see discussion in main text).

		Same Form?		Same Orientation?	
S-unit	#ITRs	each S-unit	each ITR	each S-unit	each ITR
1/7	2	yes	2	$^1/_3$ yes	$^2/_3$
2/5	6	yes	6	$^2/_3$ yes	4
3/14	3	$^1/_2$ yes	$1^1/_2$	$^2/_3$ yes	2
4/8	4	yes	4	$^2/_3$ yes	$2^2/_3$
5/8	2	$^1/_2$ yes	1	$^2/_3$ yes	$1^1/_3$
5/14	2	no	0	no	0
5/15	2	no	0	no	0
6/9	12	yes	12	$^1/_3$ yes	4
7/13	4	no	0	no	0
9/11	4	yes	4	$^1/_3$ yes	$1^1/_3$
9/15	2	$^1/_2$ yes	1	no	0
13/15	4	yes	4	no	0
TOTALS 12 S-units	47 ITRs	$7^1/_2$	$35^1/_2$	$3^2/_3$	16

Percentages:

Out of 12 S-units, $7^1/_2$ have the same form = 63%
Out of 12 S-units, $3^2/_3$ have the same orientation = 31%

Out of 47 ITRs, $35^1/_2$ have the same form = 76%
Out of 47 ITRs, 16 have the same orientation = 34%

This analysis indicates that the form attributes are greater descriptors of kinespheric clustering than orientation attributes.

APX. XVII.70 Directionality of the Twelve Strongest Subjective-Units
(non-consecutive ITRs included)

A histogram displays the directionality of the 12 strongest S-units. The S-units 4/8, 5/15, 6/9, and 13/15 are usually recalled in the same order and so are identified as primarily uni-directional.

S-unit	Direction	#Os	Specific Occurrences
1/7	#7, #1:	3	L5 A1 A2
	#1, #7:	1	I4
2/5	#2, #5:	4	E3 E4 D4 D5
	#5, #2:	5	E5 D3 B3 B4 B5
3/14	#3, #14:	2	F3 F5
	#14, #3:	4	E4 E5 H2 H3
+4/8	#4, #8:	1	B5
	#8, #4:	6	B4 E3 E4 E5 I3 I5
5/8	#5, #8:	1	B2
	#8, #5:	3	B3 H4 H5
5/14	#5, #14:	2	I4 I5
	#14, #5:	2	L4 L5
+5/15	#5, #15:	0	-
	#15, #5:	4	B4 B5 L1 L2
+6/9	#9, #6:	14	G3 B1 B4 B5 E2 E3 E4 F4 F5 I3 I5 L3 L4 L5
	#6, #9:	4	G4 B2 B3 E5
7/13	#7, #13:	3	B3 L2 L3
	#13, #7:	4	B2 E1 E2 E5
9/11	#9, #11:	3	H1 D3 D4
	#11, #9:	4	H5 D5 A2 A3
+9/15	#9, #15:	0	-
	#15, #9:	4	D2 D3 E3 E4
+13/15	#13, #15:	6	H4 E3 E4 A3 A4 A5
	#15, #13:	2	H2 E5

#Os - The number of occurrences of the S-unit in that direction.
\+ - An S-unit identified as primarily uni-directional.

APX. XVII.80 Occurrences of First Recall Position ITRs

Histograms exhibit the occurrences of kinesthetic-items organised into first position ITRs (for convenience here these are abbreviated as F-units).

Item	F-unit	#Os	Specific Occurrences
#1	F/1	2	I1-I2
#2	-		
#3	-		
#4	-		
#5	-		
#6	-		
#7	F/7	9	A1-A2 G2-G3 I2-I3 J3-J4-J5
#8	F/8	5	H1-H2-H3-H4-H5
#9	F/9	2	L1-L2
#10	-		
#11	-		
#12	-		
#13	F/13	2	E3-E4
#14	-		
#15	-		
#16	-		

ITEMS AND S-UNITS ORGANISED INTO THE FIRST RECALL POSITION

(reversed F/S-units and non-consecutive ITRs included)

Often an entire S-unit was organised into the first recall position (this is abbreviated here as an F/S-unit). Each occurrence of an F/S-units is listed here regardless of which item within the S-unit is recalled first. Well established F-units also occurred in non-consecutive ITRs and so these are also included here.

F/1:	J1:	F/1	F/8	H1:	F/8/7
	J2:	F/1/9		H2:	F/8
				H3:	F/8/7
F/7:	A1:	F/7/1		H4:	F/8/5
	A2:	F/7/1		H5:	F/8/5
	G2:	F/7/14			
	G3:	F/7/14	F/9	B1:	F/9/6/13
	G4:	F/14/7		B2:	F/6/9
	G5:	F/7		B4:	F/9/6/13
	I2:	F/7		L1:	F/9/8
	I3:	F/7		L2:	F/9/8/6
	I5:	F/7		L3:	F/8/9/6
	J3:	F/7		L5:	F/9/6/8
	J4:	F/7			
	J5:	F/7	F/13	E3:	F/13/15/9/6
				E4:	F/13/15/9/6

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Numbers in brackets indicate the section(s) where the work is cited.

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