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RHYTHMIC MOTION TO MEASURE AND FACILITATE NEUROLOGICAL RECOVERY: THEORY, PRACTICE AND EARLY CASE EXPERIENCE

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INTRODUCTION

Rhythm is an ubiquitous feature of the universe. Galaxies rhythmically expand and contract, and so do the hearts of men. One of man's earliest concepts--the microcosm and macrocosm--expressed the belief that the cycles of man's life are a reflection of the rhythm of the planets.

The concepts of Time and Rhythm remain elusive for science and philosophy, while artists try to help find a meaning in the small amount of time that we call our lives. Modern physics tells us that time is equivalent to space (if multiplied by a factor "c", equal to the speed of light). What does this really mean? Why can't we walk backward in time as we do in space?

And in the world of rehabilitation medicine, we try to help our patients adapt to the irreversible changes that time brings them. Unfortunately, we can't multiply our patients' lives by " minus 'c' "(though they do fantasize too often that we can) to restore a function that they have lost for the remainder of their time on Earth.

Despite the tremendous emotional and intellectual involvement with time, the use of time, in the form of rhythm can help the disabled and ill, though it is rarely used for this purpose. Music, a form of rhythmic auditory stimulation, usually accompanied by movement (called dance) has evolved along with man. Is music a form of diversion, or is it a need? Can a society exist with a deficiency of music?

In the field of psychiatry, music and dance therapy have evolved to help the patient therapeutically express his/her emotional life. However, the only time that one hears music in other areas of medicine is in the form of Muzak in an office, an elevator, or while on hold on the phone.

The entire human organism, from the atoms to the organs, is rhythmically based (55-62). Evidence mounts to suggest that every therapeutic intervention has it's optimal rhythm, including frequency of administration, duration of each treatment, best time or times of day,and other factors. Recently, it has become clear that even modern medicine's prototypic disease, diabetes, often cannot be adequately treated by the rhythmic administration of insulin at a frequency of twice a day.

The original impetus for this paper and its associated research came from a project that the author has reported elsewhere on the use of audio-taped exercises as an adjunct to therapy in the hospital and home. Originally, these audio-tapes were conceived of and used to record <u>routine</u> rehabilitation programs (i.e. range-of-motion, strengthening, etc.), with a musical background, to facilitate compliance, cost-effectiveness and precision. The purpose of the background music was strictly to create a conducive atmosphere.

However, after early work with this new modality, the author began to invent exercises to allow the patient to move with the musical rhythms on the tape. It soon became apparent that there were unique benefits derived from what will hereafter be referred to as the "auditory rhythmic context".

Because space limitations prevents an in-depth discussion of the theory and application of rhythm to all of rehabilitation medicine, the author will limit this discussion to some basic neurophysiology of rhythm, and the application of this data to both measure and treat spasticity.

THEORY: RHYTHMIC MOTION IN AN AUDITORY RHYTHMIC CONTEXT

The use of rhythm to facilitate nervous recovery has rarely been reported. Hellebrandt and Houtz (41), in the 1950's, demonstrated that strength and endurance can be increased by progressing pace rather than resistance--a finding rarely applied.

DeLateur, Lehmann and Giaconi (18) used rhythmic pacing to study the effects of fatigue and rest on the development of strength. However, they only used one pacing, used a metronome as the rhythmic source (which is unpleasant), and did not acknowledge nor consider the auditory and rhythmic contribution to their experimental design.

Safranek, Koshland and Raymond (73) have shown that moving to rhythm causes motor units to synchronize; while Milner-Brown, Stein and Lee (55) have shown that moving at different paces requires different synchronization patterns. However, this finding also has been rarely applied.

Along the same line, Kottke has written much about the training of coordination (43, 44, 45). He has demonstrated that millions of repetitions of exact movements are necessary to create quality motor engrams.

While specific guidelines were outlined, ways of implementing these millions of precise movements were not offered.

Rhythmic stimulation, rhythmic motion, and the ensuing relaxation tune down the perceptual systems and enable them to detect small differences, as described by the Weber-Fechner law of perception (77). Such increased awareness is necessary for, and accelerates learning. Therefore, rhythmic exercises are essentially using biofeedback principles (5, 9, 87) without their cost or technology.

Rhythm and the Vestibulo-Cerebellar System

The use of rhythmic motion within an auditory rhythmic context has some similarities to the Sensory Integration (SI) Method developed by A. Jean Ayres (3). Dr. Ayres has shown the primacy of the vestibular system in organizing nervous system input and output. Though designed primarily for a pediatric population with developmental delays, SI therapy has been demonstrated to help even the college student with low achievement (2). Levinson (70) has suggested that one possible etiology of dyslexia is an improperly functioning vestibular system. The auditory and vestibular system have a common evolution, anatomy and neurophysiology (31). One can hypothesize that if vestibular stimulation has a therapeutic effect, so might auditory stimulation.

In addition, certain auditory (and visual) stimuli can create a sense of motion through their <u>direct</u> effect on the vestibular system (39, 25). By using stereo tapes, any sound can easily be made to move from side to side, creating a sense of horizontal, linear or rotatory motion. This effect can be further magnified by listening through headphones. Music from popular movies such as <u>Flashdance</u> and <u>Star Wars</u> use such an auditory (and visual) influence on the vestibular system to create a "moving" experience.

Most work on the vestibular system has been done by the space program. One study has shown that assymetric auditory stimulation at a frequency of 1500 cycles/sec, or symmetric stimulation at 550 cycles/sec has a negative effect on a balance task (39). However, this study was performed at loud volumes (95 decibels), and the effect on the vestibular system may be mechanical rather than neurophysiological.

Based on the above, it is possible that auditory stimulation of varying temporal patterns (rhythm), pitch (melody), and tonal quality (timbre) can have various neurophysiological and neuropsychological effects upon the vestibular system. When listening to music, the urge to move, and possibly the elation that we feel may be vestibular, rather than emotional. Furthermore, the vestibular-cerebellar system has a significant relationship to the limbic system (29, 37, 84).

Neurophysiological Considerations

There are several differences between the ways in which the nervous system processes visual and auditory input--important because current society is strongly visually based:

1) The auditory system develops earlier and is more closely related to the vestibular system.
2) There is no such thing as a static sound, while visual stimuli are often static. This is why we dance to sound, rather than to light.
3) The auditory system has a more intimate connection with the general organizing systems of the brainstem, such as the reticular activating system (11). This effect may be enhanced when movement is coordinated with rhythmic breathing (which is also processed low in the brainstem (23).
4) The relationship between sound and sight is also demonstrated by the common experience that vision usually dominates over the other senses (especially in modern society). It is often necessary to close the eyes to gain full appreciation of auditory, kinesthetic and tactile. However, we were given the ability to close our eyes. Never our ears.

In aphasia, the non-dominant hemisphere can understand language and movement patterns within a musical context, amd has been used to reeducate speech, using a technique called "Melodic Intonation Therapy".

Musical perception involves both right and left-brain function and may integrate the two (7, 13, 15, 16, 72).

There is data that suggests that after unilateral injury, the dysfunctional cortex can permanently alter the function of the contralateral, organically intact cortex (79). The author hypothesizes that the reverse can also occur--that is, that the intact side can help the affected side to reorganize, via intact pathways.

The author proposes another possible mechanism by which the auditory rhythmic context can effect the nervous system. Gibson (33) has shown that the only time that perfectly symmetric auditory stimulation exists, in the face of head motion, is when the listener is speaking. Children learn to think by talking to themselves, and then by internalizing this symmetric voice (90). Thus when one listens through headphones, the stimulus of course does not change with head motion, and the nervous system processes this input, on some level, as a form of thinking.

The theoretical basis of this work differs it from music and dance therapy, which are used to facilitate emotional expression, and do not specifically address the physiology of nervous recovery (1, 6). This work is also different from popular aerobic and exercise programs, such as those endorsed by Jane Fonda (26), as the goals of these programs is cardiovascular and musculoskeletal fitness, not neurological recovery or increased perceptual awareness. However, there are some similarities to activities (recreation) therapy (12, 64), in that several neurophysiological systems are integrated when one conducts a purposeful activity (34).

In addition, the powerful, though rarely studied effect of music on those elusive entities that science labels will, motivation and spirituality are all called into play.

Rhythm and Time Distortion

The perception of time can be altered by many factors, including rhythm (67). Though not studied, it is a common experience that the same activity (such as strenuous exercise, or a tedious one) performed to rhythm seems quicker and easier. Part of this ease is probably due to better synchronization of motor units (55). However, apart from the motor component of time distortion, there is a perceptual component. Auditory rhythm produces an effect equivalent to an optical illusion--it causes incorrect judgements of time due to some (as of yet unstudied)neuropsychological effect. It may also be that if time is a sense, listening to music may cause us to ignore this sense, as we can ignore other senses.

Time distortion is a common experience of dreams and hypnotic trance (14). Time can seem either compressed or expanded by of a factor of ten or more. As an example of time expansion, dreams which seem to last hours have been recorded to physiologically last only seconds, while we experience time compression often in waking life--as everyone knows, "time flies when one has fun".

CLINICAL APPLICATIONS

In designing a paced exercise program, designed to facilitate neurvous as well as muscular recovery, several variables exist, such as:

1) The exercise rate itself
2) The ratio of exercise to rest
3) The rhythmic qualities of the exercise and rest (apart from rate)
4) Coordination of exercise rate with breathing rate
5) Coordination of breathing cycle with exercise/rest cycle
   (i.e. whether to exert with inhalation or exhalation)
6) Ratio of inhalation time to exhalation time

To gain information about these parameters, the author has conducted an extensive survey of references in exercise physiology, sports medicine, yoga, dance and other forms of neuro-muscular training. The author also tested various patterns upon himself and colleagues for several years before designing tapes for patient use. The following observations and conclusions were made, though there remains a need for formal study:

1) The body has certain inherent rhythms (see Table 1) varying from the order of 1/10 second/cycle for brain wave and neurophysiological events, to 1/2 second/cycle for consciousness (shift of attention) (83) and walking and up to one second/cycle for heart rate.

INSERT TABLE 1 HERE

The period of 4 sec/cycle is common to respiration rate, blink rate (in adults, which probably has something to do with information processing (76, 89)), immediate memory (64), and for the perception of auditory rhythm (i.e., patterns extending over 4 seconds are not perceived auditorily as belonging within one rhythmic unit (27)).

2) Blinking and breathing (and certain oro-facial movements such as chewing, swallowing and eye movements) are especially interesting movements in that their control are at the interface of cortical (conscious) and sub-cortical (unconscious) processes. Both blinking and breathing are usually controlled autonomically (and automatically), but their control can easily be taken over by conscious volition without special training. References on yoga claim that autonomic function such as heart rate, gastrointestinal activity, attention (sleep/wake) cycles can be accessed by consciously varying breathing rate (30, 51, 69). Furthermore, during certain activities (such as running), there are inherent synchronization patterns between breathing and activity cycles that are neurologically mediated (8, 36).

3) Most popular dance music (such as Michael Jackson's Thriller) has a pace of about 118 beats/minute, which is almost precisely that of average walking speed (49). (Also, most dance music is composed of units of 4 beats (measures)).

Based upon the above observations, plus the informal experimentation discussed above, the following specific guidelines are used in designing the pacing of the lesson tapes:

1) A unit of four beats is used. If a motion needs more than four beats because of its magnitude or complexity, multiples of four are used (i.e., 8, 12, 16, etc.). In most cases, each beat is one second.

2) Movement away from starting position is usually coordinated with exhalation, while return to starting is coordinated with inhalation. This is usually followed by a breathing-rest phase continuing the exhalation-inhalation rhythm.

3) Inhalation Time = Exhalation Time. Though the normal physiological inhalation/exhalation ratio is 1:2, in most exercises it more comfortable to keep the ratio one-to-one.

4) Exercise Time = Rest Time. In this way, the longer the exertion, the longer the following rest time. Also, if the patient cannot sustain exertion for the entire duration of the exercise period, the rest period begins immediately and thus the remaining exercise time is added to the given rest period. (In such a case, the rest time will be longer than the exercise time, which is appropriate for strenuous exercise. As the patient's endurance increases, the full exercise time will be used and therefore the rest time will decrease until the rest and exercise times are equal.)

RHYTHM AND SPASTICITY

Rhythm to Treat Spasticity

Spasticity can be thought of as a strictly rhythmic abberation of movement. The classic understanding of spasticity, that excessive gamma bias of the muscle spindle causes increased phasic reflexes, is indeed rhythmic. As one moves faster, spasticity increases. Weakness is due to poor coordination between muscle groups, and between agonists and antagonists (42).

The contribution of the spindle is now in question, because recent evidence indicates that the gamma motor neuron is only active during voluntary motion, even in spasticity (10, 19, 21, 28, 46, 47, 48, 78). If this is true, spasticity during passive motion cannot be explained. However, regardless of the theory, the experience of spasticity is rhythmic, as described above.

The author has been working with several patients with spasticity, who are over a year post-injury. By using audio-tapes designed with the above considerations in mind, these patients have continued to show decrease in speasticity and increase in motor control.

Rhythm to Measure Spasticity

To this date there exists no reliable, practical way to measure spasticity which doesn't entail problems with methodology or validity. However, the measurement of spasticity remains an imperitive for rehabilitation, to measure impairment and recovery, and to assess the efficacy of various therapeutic modalities. Between hospitalization for stroke, disability relaated to stroke and it's pain, and the treatment of spasticity, millions of dollars are involved.

A review of papers on measurement reveals that the technique usually involves some sort of passive motion of a spastic extremity, with a measurement of force or integrated EMG (17, 20, 74, 80, 81). However, no paper described how the temporal qualities of such motion were chosen.

Except in the case of complete spinal cord injury, which is the minority of patients with spasticity, most spastic limbs have a component of voluntary motion. It is the relation of spasticity to volition that is usually the issue, especially when pain and functional limitations are involved. Therefore, measures that are derived from strictly pasive motion are of limited clinical relevance.

In developing a rhythmic measure of spasticity, the author approaches spasticity from a perspective of time, rather than force. The apparatus is relatively simple in concept and design, though its realization requires state-of-the-art technology (see Figure 1)

INSERT FIGURE 1 HERE

Essentially the patient is provided with an auditory rhythmic pattern generated by computer. The patient has to match this rhythmic pattern py pressing on a force transducer. A series of colored lights tells the patient when the force is too low, too high, or within the desired force window (which can be adjusted for the patient). Since the important feature of the curve is it's temporal qualities, and not it's amplitude (force), the patient is free to adjust his position with respect to the measurement device. All that is necessary is that the temporal pattern be matched as best as possible.

This force curve is then subjected to a Fourier Transform Analysis, which analyzes frequency componenets of the curve. As spastic patients have problems both with inhibition and modulation of movement, the author hypothesizes that when these patients' Fourier Transforms are compared to those of normal controls, certain frequency aberrations will be found. Since this method involves auditory perception, to which both the right and left brain contribute neurophysiologically, this same method may be a way of studying soft neurological signs in adult and pediatric patients whose deficits do not manifest on routine testing. A variety of rhythmic patterns will undoubtedly need to be tried. It is possible that different diseases and sites in the nervous system will be sensitive to different rhythmic patterns.

DISCUSSION

The device discussed above is stillbeing designed and tested, so no clinical data is yet available. Hoever, as described above, the author is now applying these rhythmic principles to the treatment of several patients, with results that support the above hypotheses.

To close this discussion, the author would like to cite an article that recently appeared. Weber, et. al. (85) reported providing <u>comatose</u> patients with two forms of therapy. The control group received a standard program of passive range of motion, splinting, routine nursing care and family visits; while the treatment group received an organized sensory-motor approach, incorporating motor, auditory, and tactile input in a coordinated fashion. There were statistically significant differences in the EEG's between the two groups after four thirty-minute treatment sessions given over two days. Thus, even comatose patients can respond differently to different forms of stimulation

To extrapolate this finding into the future, one can imagine that some day comatose patients will be connected to Walkmans and computer-run motor pattern generators (to move the patient to the musical rhythm). One can further imagine typical bedside rounds on such a ward: the attending physician asking the resident what "dose" of music the patient is receiving; the resident responding that the patient is now being "treated" with Michael Jackson; and the attending scolding the resident for progressing the patient too quickly, as the patient does not yet have "rock-bearing status"!

The use of rhythm and sound to facilitate neurological recovery remains a vast, unexplored frontier.

REFERENCES

1)American Psychiatric Association: The Use of Creative Arts in Therapy. Washington DC: Am. Psychiatric Assoc. Press, 1980. (Report of a conference of the Am. Art Therapy Assoc., Am. Dance Therapy Assoc., Am. Soc. Group Psychotherapy and Psychodrama, and the Nat. Assoc. for Music Therapy on June 28-30, 1979)

2)Ayres AJ: Sensory Integration and the Child. Los Angeles: Western Psychological Services, 1979.

3)Angelo JKB: Effects of Sensory Integration Treatment on the Low-Achieving College Student. Am. J. Occ. Ther. 34: 671-675, 1980.

4)Bach-y-Rita P: Brain Plasticity as a Basis of the Development of Rehabilitation Procedures for Hemiplegia. Scand. J. Rehab. Med. 13:78-83, 1981.

5)Basmajian JV: Biofeedback: Principles and Practice for Clinicians (2nd Ed.) Baltimore: Williams and Wilkins, 1983.

6)Bernstein PL: Theory and Methods in Dance-Movement Therapy (3rd Ed.) Dubuque, Iowa: Kendall-Hunt, 1981.

7)Bhatnajar S, Andy OJ: Language in the Nondominant Right Hemisphere. Arch. Neurol. 40: 728-731, 1983.

8)Bramble DM, Carrier DR: Running and Breathing in Mammals. Science 219: 251-253, 1983.

9)Brudny J, Korein J, Grynbaum BB, Balandres PV, Gianutsos JG: Helping Hemiparetics to Help Themselves: Sensory Feedback Therapy. J.A.M.A. 241: 841-818, 1979.

10)Burke D: A Reassessment of the Muscle Spindle Contribuation to Muscle Tone in Normal and Spastic Man (with Discussion). In Feldman RG, Young RR, Koella WP: Spasticity: Discordered Motor Control. Miami: Symposia Specialists, 1980 (CIBA-GEIGY), pp. 261-286.

11)Carpenter MB, Sutin J (Eds.): Human Neuroanatomy (8th Ed.) Baltimore: Williams and Wilkins, 1983.

12)Chaiken M, Davis R, Eisner B, Levine M: Recreation Therapy. In Ruskin AP (Ed.): Current Therapy in Physiatry. Philadelphia: Saunders, 1984 (pp 51-54).

13)Clynes M (Ed.): Music, Mind and Brain: The Neuropsychology of Music. New York: Plenum Press, 1982.

14)Cooper L, Erikson M: Time Distortion in Hypnosis. Baltimore: Williams and Wilkins, 1954.

15)Critchley M, Henson RA (Eds.): Music and the Brain: Studies in the Neurology of Music. London: Heinemann, 1977.

16)Damasio AR, Damasio H: Musical Faculty and Cerebral Dominance. In Critchley M, Henson RA (Eds.): Music and the Brain: Studies in the Neurology of Music. London: Heinemann, 1977, pp. 141-155.

17)Davidoff RA: Antispasticity Drugs: Mechanisms of Action. Ann. Neurol. 17: 107-116, 1985.

18)deLateur BJ, Lehmann JF, Giaconi R: Mechanical Work and Fatigue: Their Roles in the Development of Muscle Work Capacity. Arch. Phys. Med. Rehabil. 57: 319-324, 1976.

19)Delwaide PJ: Contribution of Human Reflex Studies to the Understanding and Management of the Pyramidal Syndrome. In Shahani BW (Ed.): Electromyography in CNS Disorders: Central EMG. Boston: Butterworth, 1984, pp. 77-110.

20)Delwaide PJ: Electrophysiological Analysis of the Mode of Action of Muscle Relaxants in Spasticity. Ann. Neurol. 17: 90-95, 1985.

21)Dimitrijevic MR: Neurocontrol of Chronic Upper Motor Neuron Syndromes. In Shahani BW (Ed.): Electromyography in CNS Disorders: Central EMG. Boston: Butterworth, 1984, pp. 111-128.

22)Divney PL: The Rhythmic Perception of Micro-Melodies: Detectability by Human Observers of a Time Increment Between Sinusoidal Pulses of Two Different, Successive Frequencies. In Gordon E (Ed.): Experimental Research in the Psychology of Music: 7. Iowa City: U. of Iowa Press, 1971, pp. 41-130.

23)Euler C von: On the Central Pattern Generator for the Basic Breathing Rhythmicity. J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 55: 1647-1659, 1983.

24)Evarts EV, Froom C, Kroller J, Jennings VA: Motor Cortex Control of Finely Graded Forces. J. Neurophysio. 49: 1199-1215, 1983.

25)Farber SD: Neurorehabilitation: A Multisensory Approach. Philadelphia: Saunders, 1982.

26)Fonda J: Jane Fonda's Workout Book. New York: Simon and Schuster, 1981.

27)Fraisse P: Multisensory Aspects of Rhythm. In Walk RD, Pick HL (Eds.): Intersensory Perception and Sensory Integration. New York: Plenum Press, 1981, pp. 217-248.

28)Freund HJ, Hefter H, Homberg V: Motor Unit Activity in Motor Disorders. In Shahani BW (Ed.): Electromyography in CNS Disorders: Central EMG. Boston: Butterworth, 1984, pp. 29-44.

29)Frick RB: The Ego and the Vestibulocerebellar System: Some Theoretical Perspectives. Psychoanalytic Quarterly 51: 93-122, 1982.

30)Funderbirk J: Science Studies Yoga. Honesdale, Penn.: Himalayan Internat. Inst., 1977.

31)Geldard FA: The Human Senses (2nd Ed.) New York: Wiley, 1972.

32)Gellhorn E: Motion and Emotion: The Role of Proprioception in the Physiology and Pathology of the Emotions. Psychol. Rev. 71:457-472, 1964.

33)Gibson JJ: The Senses Considered as Perceptual Systems. Boston: Houghton Mifflin, 1966, pp. 70-96. (reprinted 1983 by Waveland Press, Prospect Heights, Ill.)

34)Gliner JA: Purposeful Activity in Motor Learning Theory: An Event Approach to Motor Skill Acquisition. A.J.O.T. 39: 28-34, 1985.

35)Gordon E: Toward the Development of a Taxonomy of Tonal Patterns and Rhythmic Patterns: Evidence of Difficulty Level and Growth Rate. In Gordon E (Ed.): Experimental Research in the Psychology of Music:**. Iowa City: U. of Iowa Press, 1974, pp. - .

36)Grillner S: Neurobiological Bases of Rhythmic Motor Acts in Vertebrates. Science 228: 143-149, 1985.

37)Hamilton NG, Frick RB, Takahashi T, Hopping MW: Psychiatric Symptoms and Cerebellar Pathology. Am. J. Psychiatry 140: 1322-1326, 1983.

38)Harlow, H: The Nature of Love. Amer. Psychol. 13:673-685, 1958.

39)Harris CS, Sommer HC: Human Equilibrium During Acoustic Stimulation by Discrete Frequencies. USAF AMRL Technical Report 68-7, 1968. (United States Air Force Aerospace Medical Research Labs)

40)Hecox B, Levine E, Scott D: Dance in Physical Rehabilitation Phys. Ther. 56: 919-924, 1976.

41)Hellebrandt FA, Houtz MS: Methods of Muscle Training: The Influence of Pacing. Phys. Ther. Rev. 38: 319-322, 1958.

42)Humphrey DR, Reed, DJ: Separate Cortical Systems for Control of Joint Movement and Joint Stiffness: Reciporical Activation and Coactivation of Antagonist Muscles. In Desmedt JE: Motor Control Mechanisms in Health and Disease. New York: Raven Press, 1983, pp. 347-372.

43)Kottke FJ, Halpern D, Easton JKM, Ozel AT, Burrill CA: The Training of Coordination. Arch. Phys. Med. Rehabil. 59: 567-572, 1978.

44)Kottke FJ: From Reflex to Skill: The Training of Coordination. Arch. Phys. Med. Rehabil. 61:551-561, 1980.

45)Kottke FJ: Therapeutic Exercise to Develop Neuromuscular Coordination. In Kottke FJ, Stillwell GK and Lehmann JF (Eds.): Krusen's Handbook of Physical Medicine and Rehabilitation (3rd Ed.) Philadelphia: W.B. Saunders, 1982. (pp403-426).

46)Lance JW: Pyramidal and Extrapyramidal Disorders. In Shahani BW (Ed.): Electromyography in CNS Disorders: Central EMG. Boston: Butterworth, 1984, pp. 1-18.

47)Lance JW: Symposium Synopsis. In Feldman RG, Young RR, Koella WP: Spasticity: Discordered Motor Control. Miami: Symposia Specialists, 1980 (CIBA-GEIGY), pp. 485-494.

48)Landau WM: Spasticity: What Is It? What Is It Not? In Feldman RG, Young RR, Koella WP: Spasticity: Discordered Motor Control. Miami: Symposia Specialists, 1980 (CIBA-GEIGY), pp. 1-16.

49)Lehmann JF: Gait Analysis: Diagnosis and Management. In Kottke FJ, Stillwell GK, Lehmann JF (Eds.): Krusen's Handbook of Physical Medicine and Rehabilitation (3rd Ed). Philadelphia: Saunders, 1982, p. 87.

50)Levinson HN: A Solution to the Riddle Dyslexia. New York: Springer-Verlag, 1980.

51)Lidell L, Narayani, Rabinovitch G: The Sivananda Companion to Yoga. New York: Simon & Schuster, 1983.

52)Lourie RS: The Role of Rhythmic Patterns in Childhood. Am. J. Psychiatry 105: 653-660, 1949.

53)Merzenich MM, Kaas JH, Wall J, Nelson RJ, Sur M, Felleman D: Topograpghic Reorganization of Somatosensory Cortical Areas 3B and 1 in Adult Monkeys Following Restricted Deafferentation. Neuroscience 8: 33-35, 1983.

54)Michon JA: Programs and "Programs" for Sequential Patterns in Motor Behavior. Brain Res. 71: 413-424, 1974.

55)Milner-Brown HS, Stein RB, Lee RG: Synchronization of Human Motor Units: Possible Roles of Exercise and Supraspinal Reflexes. Electroenceph. Clin. Neurophysio. 38: 245-254, 1975.

56)Minors DS, Waterhouse JM: Circadian Rhythms and the Human. Bristol: Wright, 1981.

57)Minors DS, Waterhouse JM: Rhythms in Mental Performance. In Minors DS, Waterhouse JM: Circadian Rhythms and the Human. Bristol: Wright, 1981, pp. 120-139.

58)Minors DS, Waterhouse JM: Rhythms in the Infant and Aged. In Minors DS, Waterhouse JM: Circadian Rhythms and the Human. Bristol: Wright, 1981, pp. 166-186.

59)Minors DS, Waterhouse JM: Clinical Implications. In Minors DS, Waterhouse JM: Circadian Rhythms and the Human. Bristol: Wright, 1981, pp. 245-271.

60)Minors DS, Waterhouse JM: Sleep and Wakefulness. In Minors DS, Waterhouse JM: Circadian Rhythms and the Human. Bristol: Wright, 1981, pp. 95-119.

61)Minors DS, Waterhouse JM: Cardiovascular, Respiratory , Metabolic and Gastrointestinal Rhythms. In Minors DS, Waterhouse JM: Circadian Rhythms and the Human. Bristol: Wright, 1981, pp. 41-67.

62)Minors DS, Waterhouse JM: Introduction and Methods of Study. In Minors DS, Waterhouse JM: Circadian Rhythms and the Human. Bristol: Wright, 1981, pp. 1-23.

63)Moffroid MT, Whipple RH: Specificity of Speed of Exercise. Phys. Ther. 50: 1692-1700, 1970.

64)Mosey AC: Activities Therapy. New York: Raven Press, 1973.

65)Norman DA: Memory and Attention (2nd Ed.). New York: Wiley, 1976.

66)Olson HF: Music, Physics and Engineering (2nd Ed.) New York: Dover, 1967.

67)Ornstein RE: On the Experience of Time. Baltimore: Penguin, 1969.

68)Ostrander S, Shroeder L: Super-Learning. New York: Dell, 1979.

69)Rama S, Ballentine R, Hymes A: Science of Breath: A Practical Guide. Honesdale, Penn.: Himalayan Internat. Inst., 1979.

70)Rimoldi HJA: Personal Tempo. J. Abnormal Soc. Psychol. 46: 283-303, 1951.

71)Robertson SS, Dierker LJ, Sorokin Y, Rosen M: Human Fetal Movement: Spontaneous Oscillations Near One Cycle per Minute. Science 218: 1327-1330, 1982.

72)Roederer JG: Physical and Neuropsychological Foundations of Music: The Basic Question. In Clynes M (Ed.): Music, Mind and Brain: The Neuropsychology of Music. New York: Plenum Press, 1982, pp 37-46.

73)Safranek MG, Koshland GF, Raymond G: Effect of Auditory Rhythm on Muscle Activity. Phys. Ther. 62: 161-168, 1982.

74)Sahrmann SA, Norton BJ, Bomze HA, Eliasson SG: Influence of the Site of the Lesion and Muscle Length on Spasticity in Man. Phys. Ther. 54: 1290-1297, 1974.

75)Smoll FL: Development of Rhythmic Ability in Response to Selected Tempos. Perceptual and Motor Skills 39: 767-772, 1974.

76)Stevens JR, Livermore A: Eye Blinking and Rapid Eye Movement: Pulsed Photic Stimulation of the Brain. Exp. Neurol. 60: 541-556, 1978.

77)Stevens SS: Mathematics, Measurement and Psychophysics. In Stevens SS (Ed.): Handbook of Experimental Psychology. New York: Wiley, 1951, pp. 1-50.

78)Struppler A: Control of Isometric Contractions in Patients Suffering from Various Lesions of the Sensorimotor System. In Shahani BW (Ed.): Electromyography in CNS Disorders: Central EMG. Boston: Butterworth, 1984, pp. 129-142.

79)Towe AL, Mann MD: Effect of Strychnine on the Primary Evoked Response and on the Cortigofugal Reflex Discharge. Exp. Neurol. 39: 395-413, 1973.

80)Urbscheit N, Bishop B: Effects of Cooling on the Ankle-Jerk and H-Response. Phys. Ther. 50: 1041-1049, 1970.

81)Urbscheit N, Johnston R, Bishop B: Effects of Cooling on the Ankle-Jerk and H-Response in Hemiplegic Patients. Phys. Ther. 51: 983-990, 1971.

82)Valbo AB, Hagnarth K-E, Torebjork HE, Wallin BG: Somatosensory, Proprioceptive, and Sympathetic Activity in Human Peripheral Nerves. Physiol. Rev. 59: 919-957, 1979.

83)Vince MA: The Intermittency of Control Movements and the Psychological Refractory Period. Br. J. Psychol. 38: 149-157, 1948.

84)Watson PJ: Non-motor Functions of the Cerebellum. Psychol. Bull. 85: 944-967, 1978.

85)Weber PL: Sensorimotor Therapy: Its Effect on Electroencephalograms of Acute Comatose Patients. Arch. Phys. Med. Rehabil. 65: 457-462, 1984.

86)Welford AT: On the Sequencing of Action. Brain Res. 71: 381-392, 1974.

87)Wolf SL: Electromyographic Biofeedback Applications to Stroke Patients. A Critical Review. Phys. Ther. 63: 1448-1455, 1983.

88)Woodrow H: Time Perception. In Stevens SS (Ed.): Handbook of Experimental Psychology. New York: Wiley, 1951, pp. 1224-1236.

89)Zametkin AJ, Stevens JR, Pittman R: Ontogeny of Spontaneous Blinking and of Habituation of the Blink Reflex. Ann. Neurol. 5: 453-457, 1979.

90)McGuigan FJ: Thinking: Studies of Covert Language Processes. New York: Appleton-Century-Crofts, 1966.

Table 1: Natural Rhythms and Tempos

Phenomenon	Seconds/Cycle
Neurochemical	10^{-6}
Neurophysiological	10^{-3}
Brain Waves	10^{-1}
Consciousness	0.50
Walking One Step	0.50
Heart Rate	0.60-1.00
Chewing	0.80.1.25
Blinking	4.00
Breathing	3-5
Perceived Rhythm	4
Immediate Memory	4
Short-Term Memory	180 (3 minutes)
Attention/ Endocrine	5400 (90 minutes)
Circadian (Day)	24 hours
Estrous (Month)	28 days
Year	365.25 days
7-Year Cycle	0-7-14-21-28-35-42-49- 56-63-70-77-84-91-98-...

FIGURE 1: SAMPLING TAPPING DATA

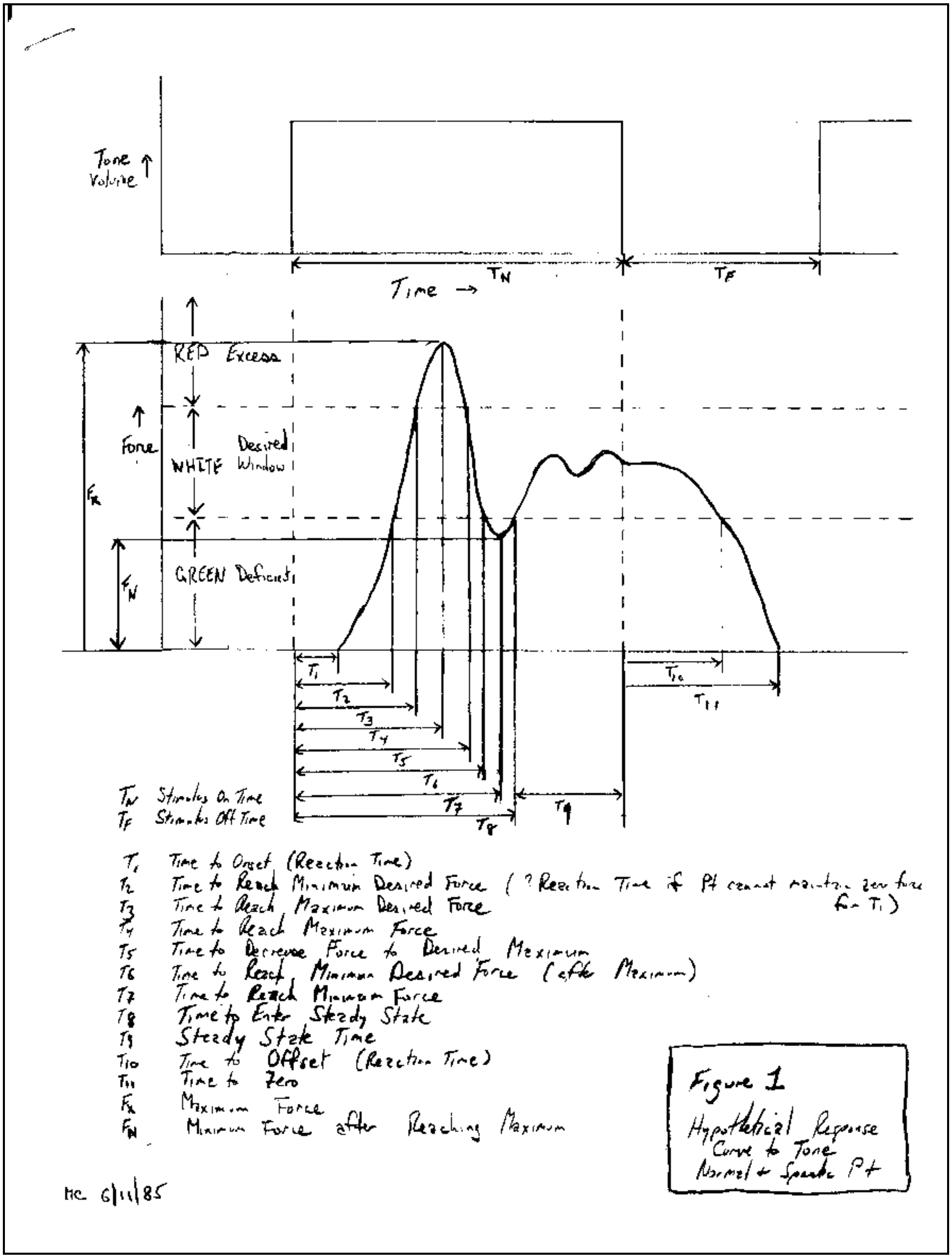

FIGURE 2: BLOCK DIAGRAM FOR CAPTURING TAPPING DATA