coop
CF-A4SN
70

報告番号 甲第 2902 号

①

Effect of optokinetic stimulation on human balance recovery in unexpected forward fall

(予期しない前方転倒でのヒトの平衡回復における視運動刺激の影響)

寶珠山 稔

寶珠山 稔

論　文　目　録

報告番号	※　第　　　号	氏名	實珠山　稔

主論文

題目　　冊

Effect of optokinetic stimulation on human balance recovery
in unexpected forward fall
（予期しない前方転倒でのヒトの平衡回復における視運動刺激の影響）

Neuroscience Research 掲載予定
Japan Neuroscience Society (Elsevier) 22枚

（既に印刷公表したものについては、その方法および年月日、未公表のものについては、公表の方法および時期を記入すること。）

副論文

題目　　冊

Effect of optokinetic stimulation on the H reflex in humans
（ヒトのH反射における視運動刺激の影響）

Japanese Journal of Physiology 44巻１号　1994年２月号　掲載予定
The Physiological Society of Japan (Center for Academic Publication) 16枚

（　同　　上　）

参考論文

題目　　冊

（　同　　上　）

主　論　文

Effect of optokinetic stimulation on human balance recovery in unexpected forward fall

M. Hoshiyama[1], S. Watanabe[2], Y. Kaneoke[1], Y. Koike[1] and A. Takahashi[1]

[1]Department of Neurology, Nagoya University of Medicine, 65 Tsuruma-cho, Showa-ku, Nagoya, 466 Japan

[2]Department of Equilibrium Adaptation Research, Division of Higher Nervous Control, Research Institute of Environmental Medicine, Nagoya University, Furo-cho, Chikusa-ku, Nagoya, 464-01 Japan

予期しない前方転倒でのヒトの平衡回復における視運動刺激の影響

寳珠山 稔、渡邊　悟、金桶 吉起、古池 保雄、高橋　昭

Correspondence to: Minoru. Hoshiyama
Department of Neurology,
Nagoya University of Medicine, 65 Tsuruma-cho,
Showa-ku, Nagoya, 466 Japan
Tel. 052-741-2111
FAX　052-733-0029

Summary

We examined whether optokinetic stimulation (OKS) affects balance recovery in an unexpected forward fall. Ten healthy male subjects participated in the study. Each was held in an initial, leaning-forward position supported by a cable connected to a strong magnet which enabled unpredicted release. Instruction was given to move against forward fall by taking steps. To evaluate the relation between OKS velocities and balance recovery, ten stages of OKS velocities ranging from -100 (upward) degree/sec to +100 (downward) degree/sec were presented randomly. Balance recovery against forward fall was characterized by the reaction time, heel off, maximum vertical push, and heel contact. The latencies of these events decreased as the downward velocity of OKS increased; the latency increased with the increment in the upward velocity of OKS. Changes in the latencies of the parameters took place in the early phase, in which the parameters of balance recovery depended little on the proprioceptive afferents from the lower limbs. This suggests that vection induced by the OKS affected the condition of the motor program which controls the initiation of the motor response. In other words, information from the visual system may modulate the condition of the motor program before the onset of movement.

Key words: Human posture; Optokinetic stimulation; Forward fall; Balance recovery

Introduction

Postural control by human subjects always is accompanied by the integration of information from the visual, vestibular and proprioceptive systems. Although numerous studies have examined the effects of the mechanism of visual flow on the control of balance, the relation of motor control to visual flow is not fully understood. In reports of the roles of visual information in postural control, optokinetic stimulation (OKS) has been shown to be one of the most effective types of experimental visual stimulation. OKS is of particular interest because of its spectacular effects which cause the illusion of self-motion called 'vection'(Fischer and Kornmüller, 1930; Brandt et al., 1973; Berthoz et al., 1975; Nashner and Berthoz, 1978; Andersen, 1986). Under OKS subjects may report vection without postural change, or change their posture without reporting vection (Mauritz, 1977). When a pattern that covers the greater part of the visual field moves unidirectionally like a stream, subjects experience body inclination that is like being pulled into the stream pattern. In the absence of actual motion, vection evokes the perception of self-motion or of discomfort like that of motion sickness in susceptible subjects (Dichgans and Brandt, 1973; Tiande and Jingshen, 1991).

The roles of visual flow in motor control in human (Dichgans et al., 1972; Brandt et al., 1973; Dichgans and Brandt, 1973; Soechting and Berthoz, 1979) and experimental animals (Dichgans et al., 1973; Henn et al., 1974; Keller, 1976; Berthoz et al., 1979) have been analyzed under OKS. The roles of visual flow in balance control (Dichgans et al., 1972; Lestinne et al., 1977; Ichikawa and

Watanabe, 1990, 1992) and in locomotor control (Johansson, 1977; Stoffregen et al., 1987; Pailhous et al., 1990) also have been investigated. Although the postural and behavioral changes caused by vection have been discussed, the mechanism is little understood.

When a person moves in one direction, apparent movement of the entire visual field in the direction opposite to the displacement of the body occurs. This movement of the visual field causes a sensation of body displacement for the person. Visual information about the visual flow interacts with information from the vestibular (Allum et al., 1976) and proprioceptive systems which change according to the movement of the body as a reflex-like reaction. In unpredicted forward fall, the unexpected body movement causes apparent movement of the visual field. The magnitude of the movement of the visual field corresponds directly to the displacement of the body under the above conditions. In balance recovery as well, one would predict that compensatory reactive movement would be influenced by visual information. Can experimentally induced changes in visual flow, such as OKS, cause unintentional modulation of balance recovery? Compensatory reaction against an unexpected forward fall, at least the early part of the reaction, is provided by the motor program that is programmed with information from the visual, vestibular, and proprioceptive systems before the fall begins. If the compensatory reaction is affected by the OKS, then it should be possible to study part of the role of OKS in the motor program.

To determine how the OKS affects the motor program's regulation of balance recovery, we decided to clarify the effect of the OKS on balance recovery movement from an unexpected forward fall. An initial inclined posture that provoked forward fall provided a convenient experimental paradigm. On one hand, compensatory reactions in unexpected forward fall are reproducible (Do et al., 1982); and, using our method information from the vestibular and proprioceptive systems can be kept unchanged until the forward fall from the inclined posture.

Method

Procedure (Fig.1): Each subject was held in equilibrium in an initial forward-inclined posture by a wide pelvic belt connected to a horizontal cable mounted on a fixed frame. The subject stood on the force platform (AMTI OR6-5-1) held in the initial leaned position, in which the body was straight and the arms were held along the sides of the body. The initial inclination (7 degrees) was adjusted by changing the length of the cable which was connected to a strong magnet. The reason for the choice of this angle of inclination was to avoid the subject's use of another strategy against forward fall, such as considerable elbow flexion, just after release (Dietz and Noth, 1978).

Do et al.(1982) reported that the latency of the later part of balance recovery, which includes the times of heel contact and heel swinging, depends on the degree of the subject's initial inclination. First the subject was instructed to gaze at a fixed spot projected on the center of a uniform white hemispherical screen (diameter 140cm) in a dark room. A random dot pattern was projected (ranging in size from dia 0.5cm to 2.0cm, and covering 87% of the visual field) on the screen. The subject was presented with a pattern that filled the greater part of his peripheral and foveal ranges of vision.

When the subject became motionless, the restraining connection was broken without warning by switching off the magnet. The instruction given was to recover balance by use of a stepping action to prevent falling down. In almost all cases, the subject responded to the inclination by executing one step, or in a few cases several steps, on the force platform itself or on the wooden staging around the platform which was at the same level. No instruction was given as to which foot should initiate the movement.

Pattern generation: This experiment was first performed while a stationary pattern was projected, after which moving patterns, designed to examine the relationship between the pattern velocity of visual flow and balance recovery, were used. To evaluate the relation between OKS velocities and balance recovery, upward and downward pattern velocities of 20, 40, 60, 80, and 100degree/sec were presented in random order. After the acceleration phase (4 degree/sec^2), the pattern was moved at constant velocity. When the subject had adapted (after 30 sec of pattern movement at constant velocity), the trials described above were carried out.

We considered three values, which are the vertical resultant of force (Rz), the antero-posterior displacement of the center of gravity (X) and the antero-posterior resultant of force (Rx), from the platform system. The force platform's axes were set so that:

(1) a negative value of Rz corresponded to the vertical resultant of force in the same direction as the earth's gravity

(2) a positive value of X corresponded to displacement of the center of gravity towards the front of the supporting area

(3) a positive value of Rx corresponded to the resultant of force

in the forward direction of the supporting area.

Bilateral surface EMGs of the tibialis anteriors and the soleus muscles were recorded simultaneously. The signals for Rz, X and Rx, as well as the EMGs, were amplified and band-pass filtered (10 to 1,500Hz) then stored on a data recorder (TEAC XR-50), after which they were transferred off-line and sampled by a signal processor with 8mega byte of central memory (7T18, NEC SAN-EI) at 1,000Hz for 1,000msec. Data acquisition from the recorder was triggered by the opening of the electrical switch that broke the restraining magnetic connection.

Ten healthy adult male subjects who were members of our university staff aged between 29 and 42 years (mean 33.2yrs) were tested. Testing was repeated at least twice for each subject. In each test, 20 trials were recorded for each OKS pattern generation. An analyses of variance (Kruskal-Wallis test) was statistical test used.

Results

First, several biomechanical parameters which effectively described the characteristics of the balance recovery process were determined. The early phase of balance recovery from forward fall, which included the period covering the release of the subject's support and the execution of the first step was analyzed. Fig.2 shows a typical recording of balance recovery by the execution of a step against forward fall. The latency of the movement was measured for the parameters Rz, X and Rx. The subject was released by the magnet switch at time 0. The reaction time, Tr, is the onset of the EMG burst in the soleus muscle of the stepping foot. To and Tc respectively indicate the times of heel off and heel contact and express the respective latencies of the first and second sharp rises of Rx. Tm is the time of maximum vertical pressure. The meanings of these biomechanical parameters in this sequence have been examined and discussed in detail by Do et al. and Bussel (Do et al., 1982; Bussel et al., 1990).

Under the condition of no OKS ($\omega=0$), all the parameters were fairly stable. Values for the 10 subjects are shown in Table. Although the mean individual values vary, individual standard deviations are small.

A comparison of parameters for each velocity of OKS, normalized at $\omega=0$, is given in Fig. 3. All values of the parameters, except for the upward OKS in the To, changed with the velocity of OKS between -40 and +60 degree/sec. For a downward OKS direction (positive velocity in the figure) all the parameters decreased with an increase in velocity up to 60 degree/sec. In the opposite direction (upward, negative velocity) they increased with velocity up to -60 degree/sec. For an OKS of more than 60 degree/sec and less than -60 degree/sec, the changes in latencies did not correspond to the velocity. The time between To and Tc (swinging time) changed similarly with the velocity of OKS, the values of the latter parameter (Tc) being markedly affected by OKS.

All the parameters had minima at the velocity of +60 degree/sec. The maxima were at -60 or at -40 degree/sec. When the velocity of OKS exceeded 60 degree/sec, vection decreased, and a fusion stream was perceived, after which the effect of OKS also decreased for all the parameters. A highly significant correlation exists between the parameters and the velocities of OKS in the range of -60 to +60 degree/sec (Kruskal-Wallis test, $P<0.01$). The 10 subjects showed similar modulations of movement.

Discussion

When the visual surroundings move in one direction, a subject maintaining upright posture may experience a perception of induced motion that feels as though the body is being pulled in the direction of movement of the visual stimulus (vection) (Dichgans and Brandt, 1973; Berthoz et al., 1975, 1979; Dichgans and Brandt, 1988). Under this condition postural imbalance may occur. This illusion is believed to result from an interaction between visual information acting and information from the vestibular and proprioceptive systems. The purpose of this study was to observe the factors changed by vection in a motor command.

Animal experiments have shown that one site at which visual and vestibular information converge is the vestibular nuclei (Dichgans and Schmidt, 1973; Henn et al., 1974; Keller 1976); but the effect of OKS on other sites is not clear and the effect of information modified by OKS on motor control is still under investigation. Results of recent OKS studies confirm that visual perception caused by body motion interacts mutually with proprioceptive information such as vestibular and muscular/tendon/joint sensations (Pailhous 1990).

In our experimental setup, information from the proprioceptive and vestibular systems remained constant as long as the subject held the initial posture. In this situation we assumed that unexpected, unintentional movement started from a position of rest and was affected by visual information. Furthermore, in our study, the initial inclined posture was relatively easy to hold when the OKS was in the vertical direction because that posture was stabilized by the cable even when the subject perceived vection. The subject could not intentionally control movement resulting from a sudden, unexpected forward fall.

Do et al. (1982, 1988) reported that the early phase in balance recovery, which includes Tr and To, could be differentiated from the following phase, which includes Tm and Tc. They reported fixed times of Tr and To in their studies, in which they observed forward falls that ensued from various inclinations of posture. Time of Tm and Tc, on the other hand, depended on the initial inclinations of posture. They concluded that the values in the preparation phase were not dependent on the initial inclination; i.e., they were little affected by proprioceptive information from the lower limbs.

Dichgans et al. (1972) argued that visual motion modulates signals from gravireceptors at some level of the nervous system, possibly via a polysynaptic spinal pathway associated with the spinal reflex. The values of Tr and To do not depend on afferents from muscles or joints, as has been observed for proprioceptive and vestibular afferents in sudden forward displacement (Bussel, 1980). Bloomberg et al. (1991a, b) showed that the vestibulo-ocular reflex, as the simplest reflex of eye movement, is easily modified by cognition of a visual image. It could be argued that the "stabilized vision" condition is artificial and places the subject to the animal in a discordant set of sensory inputs. But at the time of the selection of an adapted pattern, the release of adequate motor synergies is dependent upon an expected pattern of congruent sensory inputs (Nashner and Berthoz, 1978). Thus changes of parameters in early phase in balance recovery (Tr and To) suggest that vection modulated the condition of the motor program that controls the initiation of motor responses, including the spinal reflex or motor program in higher central nervous system.

In the subsequent phase, the values of Tm and Tc changed with the velocity of OKS. The duration of the swing of the first step was calculated from To and Tc. This swinging time (Tc-To) corresponded to the velocity of OKS. This is not due to prolongation of the reaction time, which means that OKS interacts with proprioceptive and vestibular afferences and that OKS affects the sequence of movement even after the reaction time, at least for the first step. Pailhous's report suggests that the OKS also modulates subsequent locomotive steps (Pailhous et al., 1990).

Saturation or decrease of vection has been reported for increasing stimulus velocity (Lestinne et al., 1975). In our study, the saturation effect was recognized at less than -60 and more than 60 deg/sec. This saturation, or decrease in vection, agrees with the published data (Lestinne et al., 1975; Ichikawa and Watanabe, 1990, 1992). The effect of the upward direction may, however, differ from that of the downward direction. The patterns of modulation for each parameter were not symmetric with respect to the condition without OKS. The velocities at which the parameters showed maximum value were not the same. The forward inclined posture used may be one reason for this. There was small variability for each individual in repeated trials as to the compensatory reaction during OKS, but inter-individual variations among the 10 subjects were large. This phenomenon has been reported occasionally in studies of responses to vection (Lestinne, 1975; Ichikawa, 1990).

In conclusion, results of our study suggest that vection induced by the OKS affects the condition of the motor program which controls the initiation of the motor response, including the spinal reflex or motor program in higher central nervous system.

References

Allum, J.H.J., Graf, W., Dichgans, J. and Schmidt, C.L. (1976) Visual-vestibular interactions in the vestibular nuclei of the goldfish. Exp. Brain Res., 26: 463-485.

Andersen, G.J. (1986) Perception of self-motion: psychophysical and computational approaches. Psychol. Bull., 99: 52-65.

Berthoz, A., Pavard, B. and Young, L.R. (1975) Perception of linear horizontal self-motion induced by peripheral vision (linearvection). Basic characteristics and visual-vestibular interactions. Exp. Brain Res., 23: 471-489.

Berthoz, A., Lacour, M., Soechting, J.F. and Vidal, P.P. (1979) The role of vision in the control of posture during linear motion. Prog. Brain Res., 50: 197-209.

Bloomberg, J., Melvill Jones, G. and Segal, B. (1991a) Adaptive plasticity in the gaze stabilizing synergy of slow and saccadic eye movements. Exp. Brain Res., 84: 35-46.

Bloomberg, J., Melvill Jones, G. and Segal, B. (1991b) Adaptive modification of vestibularly perceived rotation. Exp. Brain Res., 84: 47-56.

Brandt, T., Dichgans, J. and Koenig, E. (1973) Differential effects of central versus peripheral vision on egocentric and exocentric motion perception. Exp. Brain Res., 16: 476-491.

Bussel, B., Katz, R., Pierrot-Deseilligny, E., Bergego, C. and Hayat, A. (1980) Vestibular and proprioceptive influences on the postural reactions to a sudden body displacement in man. Prog. Clin. Neurophysiol., 8: 310-322.

Dichgans, J., Held, R., Young, L.R. and Brandt, T. (1972) Moving visual scenes influence the apparent direction of gravity. Science, 178: 1217-1219.

Dichgans, J. and Brandt, T. (1973) Optokinetic motion sickness and pseudo-coriolis effects induced by moving visual stimuli. Acta. Otolaryng. (Stockh.), 76: 339-348.

Dichgans, J., Schmidt, C.L. and Graf, W. (1973) Visual input improves the speedometer function of the vestibular nuclei in the goldfish. Exp. Brain Res., 18: 319-322.

Dichgans, J. and Brandt, T. (1988) Visual-vestibular interaction: effects on self-motion perception and postural control. In: R. Held, and H.W. Leibowitz, and H.L.Teuber (Eds.), Handbook of sensory physiology, Vol.Ⅷ, Perception, Springer, Heidelberg, pp.755-804.

Dietz, V. and Noth, J. (1978) Pre-innervation and stretch responses of triceps brachii in man falling with and without visual control. Brain Res., 142: 576-579.

Do, M.C., Brenière, Y. and Bouisset, S. (1988) Compensatory reactions in forward fall: are they initiated by stretch receptors? Electroencephalogr. Clin. Neurophysiol., 69: 448-452.

Do, M.C., Brenière, Y. and Brenguier, P. (1982) A biomechanical study of balance recovery during the fall forward. J. Biomechan. 15: 933-939.

Do, M.C., Bussel, B. and Brenière, Y. (1990) Influence of plantar cutaneous afferents on early compensatory reactions to forward fall. Exp. Brain Res., 79: 319-324.

Fischer, M.H. and Kornmüller, A.E. (1930) Optokinetisch ausgelöste Bewegungswahrnehmungen und optokinetischer Nystagmus. J. Psychol. Neurol.(Lpz.), 41: 273-308.

Henn, V., Young, L.R. and Finley, C. (1974) Vestibular nucleus units in alert monkeys are also influenced by moving visual fields. Brain Res., 71: 144-149.

Ichikawa, M., Watanabe, S. (1990) Postural adjustment response induced by optokinetic stimulation. Environ. Med., 34: 189-192.

Ichikawa, M., Watanabe, S. (1992) Effects of visually induced self-motion perception (vection) on upright standing posture. Jap. J. Aerospace Environ. Med., 29: (in press).

Johansson, G. (1977) Studies on visual perception of locomotion. Perception, 6: 365-376.

Keller, E.L. (1976) Behavior of horizontal semicircular canal afferents in alert monkey during vestibular and optokinetic stimulation. Exp. Brain Res., 24: 459-471.

Lestienne, F., Soechting, J. and Berthoz, A. (1977) Postural readjustments induced by linear motion of visual senses. Exp. Brain Res., 28: 363-384.

Mauritz, K.H., Dichgans, J. and Hufschmidt, A. (1977) The angle of visual roll motion determines displacement of subjective visual vertical. Percept. Psychophys., 22: 557-562.

Nashner, L. and Berthoz, A. (1978) Visual contribution to rapid motor responses during postural control. Brain Res., 150: 403-407.

Pailhous, J., Ferrandez, A-M., Flückiger, M. and Baumberger, B. (1990) Unintentional modulations of human gait by optical flow. Behav. Brain Res., 38: 275-281.

Soechting, J.F. and Berthoz, A. (1979) Dynamic role of vision in the control of posture in man. Exp. Brain Res., 36: 551-561.

Stoffregen, T.A., Schumuckler, M.A. and Gibson, E.J. (1987) Use of central and peripheral optic flow in stance and locomotion in young walkers. Perception, 16: 121-133.

Tiande, Y. and Jingshen, P. (1991) Motion sickness severity under interaction of vection and head movements. Aviat. Space Environ. Med., 62: 141-144.

Legends

Fig.1 Diagram of the experimental set up. The subject on the force platform (FP) is maintained in the leaning forward position by a restraining and releasing apparatus (M). Luminous spots are projected on the screen (SC), and the subject gazes at a fixed red center point on the screen.

Fig.2 Typical recording of a balance recovery movement. Reaction time (Tr), time of heel off (To), time of maximum vertical push (Tm), time of heel contact (Tc). Rx: variations in the antero-posterior resultant of force. Rz: variations in the vertical resultant of force. X: antero-posterior displacement of the gravity center. EMG i-SOL: EMG of the ipsilateral soleus muscle of the starting foot.

Fig.3 Differences (expressed as the ratio T/T(0)) in the normalized parameters, Tr, To, Tm, Tc, and the heel swinging times of the subjects for different visual conditions. *:Significant correlations between the parameters and the velocities of OKS (Kruskal-Wallis test, $P<0.01$).

MI-889

Table Mean values of parameters in balance recovery.

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
Reaction time (Tr,msec)	143±12	149±3	153±10	162±11	168±13	184±14	159±14	141±7	167±11	155±10
Heel off (To,msec)	156±13	170±7	180±15	181±10	200±21	247±8	185±31	152±17	188±25	181±12
Maximum vertical push (Tm,msec)	167±13	183±9	192±15	222±10	254±18	270±9	210±41	170±14	193±20	192±9
Heel contact (Tc,msec)	301±13	311±12	325±7	356±12	397±24	388±9	342±40	311±20	343±19	344±23
Heel swinging time (Tc-To,msec)	140±16	155±13	178±15	199±21	219±44	273±39	187±48	156±28	170±26	169±37

Table.

MI-889

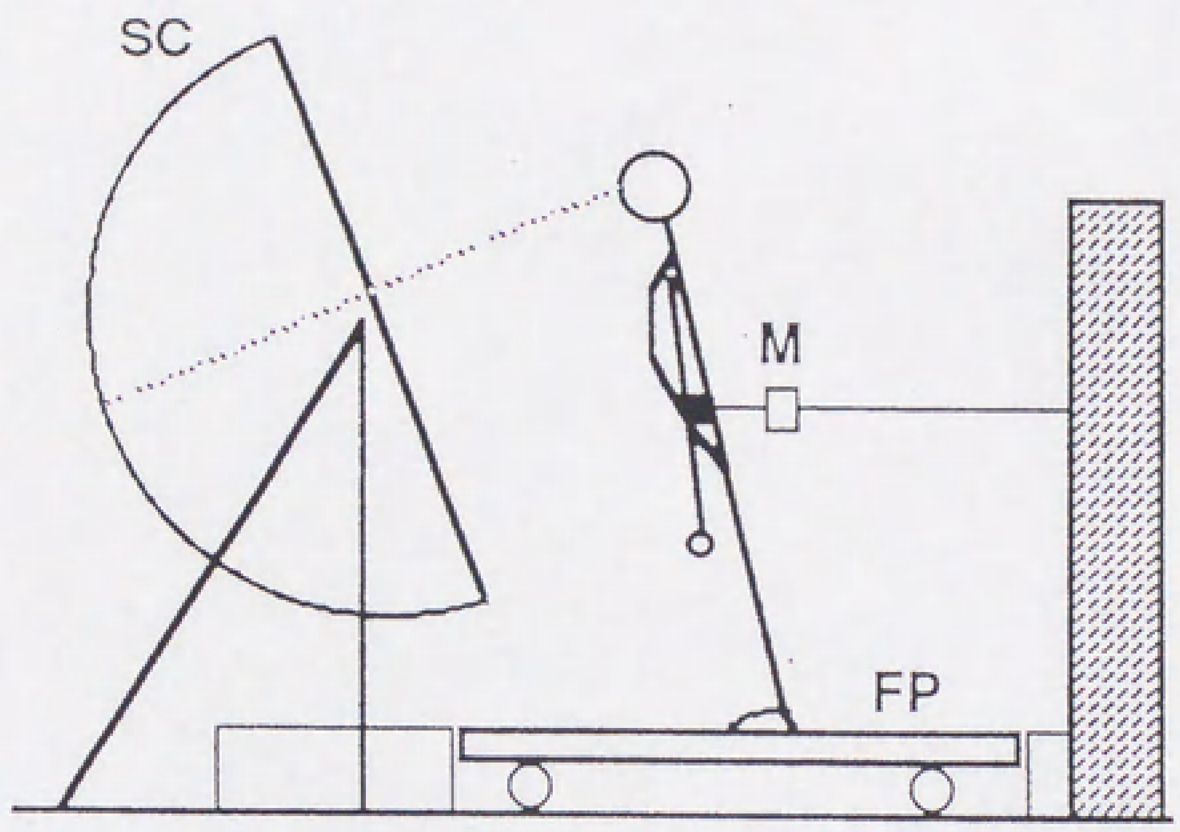


Figure 1.

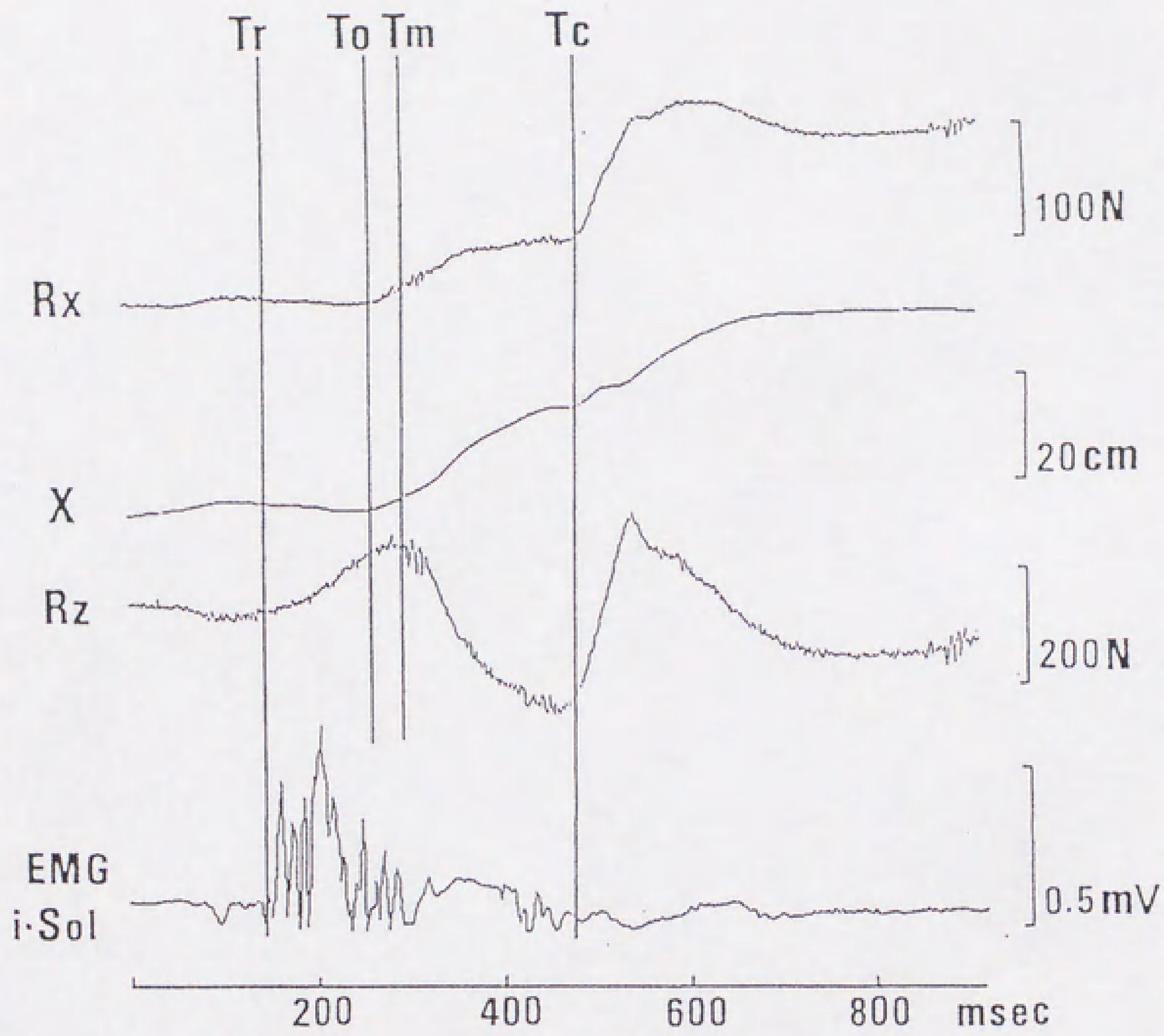

Tr
To
Tm
Tc
Rx
100N
X
20cm
Rz
200N
EMG
i·Sol
0.5mV
200
400
600
800
msec

Figure 2

MI-889

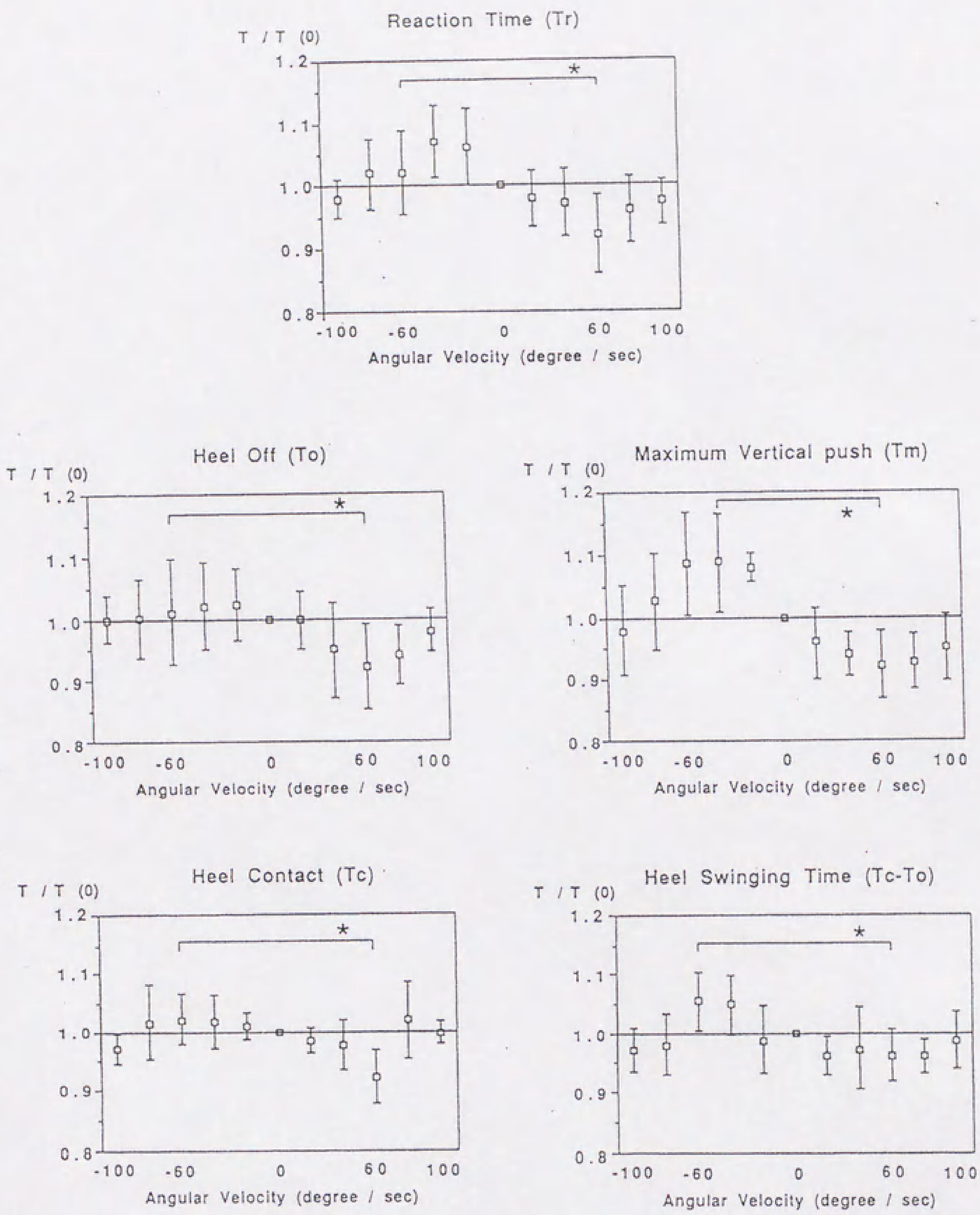
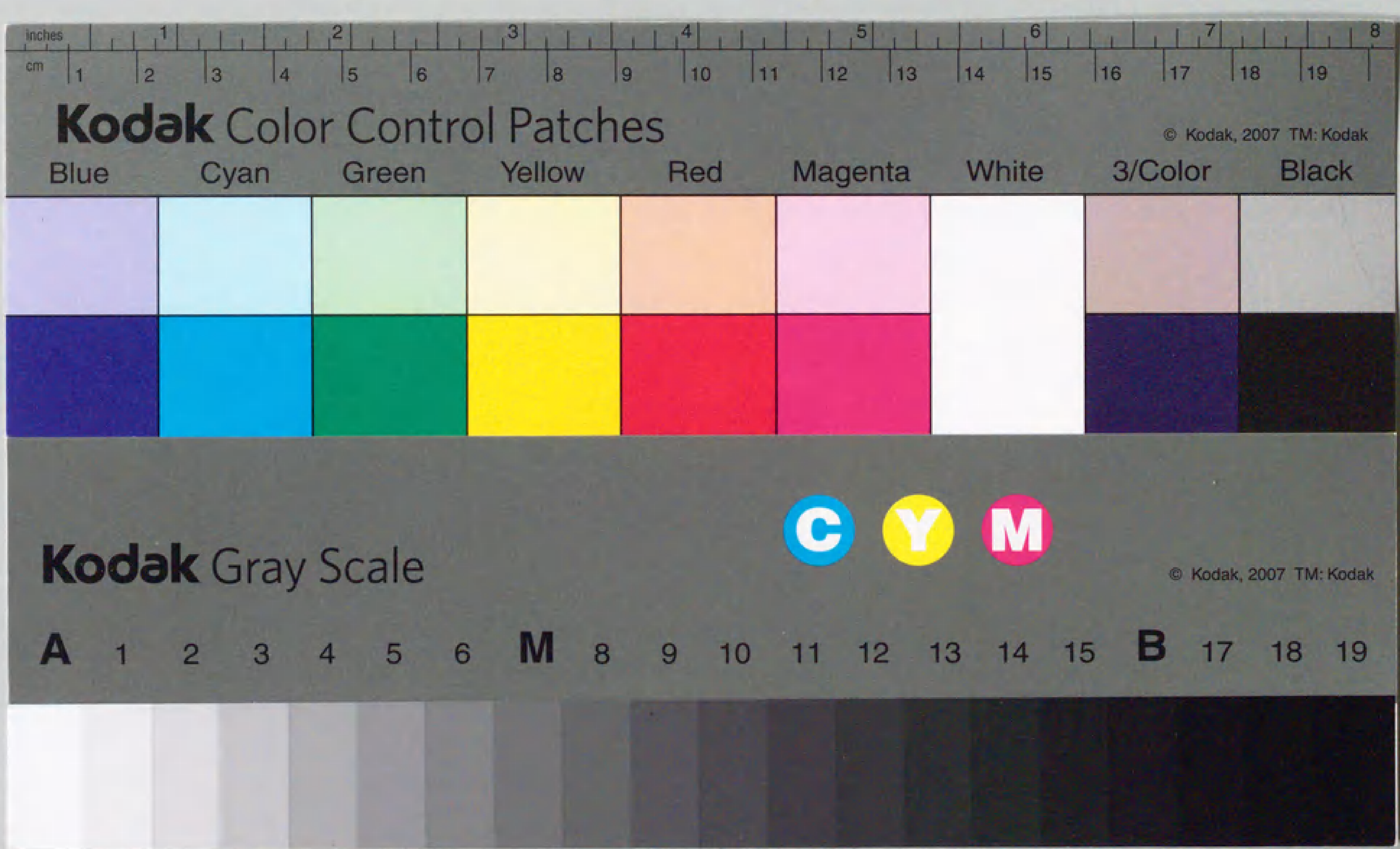


Figure 3.


Kodak Color Control Patches
© Kodak, 2007 TM: Kodak
Blue
Cyan
Green
Yellow
Red
Magenta
White
3/Color
Black
C
Y
M
Kodak Gray Scale
© Kodak, 2007 TM: Kodak
A 1 2 3 4 5 6 M 8 9 10 11 12 13 14 15 B 17 18 19