A NEW EXPERIMENTAL PROTOCOL TO QUANTITATIVELY ASSESS THE MOTOR CONTROL CAPABILITY OF LOW-BACK PAIN PATIENTS DURING DYNAMIC TRUNK MOVEMENT

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ABSTRACT

An experimental protocol was developed and tested in this study in order to quantify the motor control capability of the trunk movement for both healthy subjects and low-back pain (LBP) patients. Information processing capacity (bits/second) (Fitts, 1954) and dynamic motor performance such as flexion/extension velocity and acceleration were measured as motor control parameters under the controlled range of motion (ROM). In this study, the original experimental protocol (Kim et al., 1993, 1994) was re-designed to reduce the length of the test via a series of statistical analyses for clinical application. The accuracy of the shortened protocol was statistically examined and indicated no difference compared to the original protocol in terms of evaluating information processing capacity. This protocol was also tested among ten healthy subjects and ten LBP patients for validation purpose. The results showed that the information processing capacity was not significantly different between two groups due to the large variation although there was an apparent mean difference. Average movement time showed a significant increase in LBP patients compared to healthy subjects. In conclusion, it was found that the new short experimental protocol could quantify the motor control capability of neuromuscular system of the trunk and also showed the applicability to patient population.

INTRODUCTION

It is well known that low back pain (LBP) has been one of the most common and costly musculoskeletal problems in the working place (Spengler et al., 1986). In order to treat low-back problems as well as prevent them, it is essential to have an accurate diagnostic technique. However, based on current imaging technology such as X-ray, MRI, and CT scan, only 12-15% of LBP patient show anatomical findings (Bigos and Battie, 1990). Thus, the functional measurement technique such as range of motion (Keeley et al, 1986), strength (Triano and Schultz, 1987), and endurance (Beimborn and Morrissey, 1988) have been introduced and proven as reliable measures to evaluate the patient with low-back pain. Especially, dynamic trunk motion during flexion and extension has been studied to quantify the severity of the low-back pain, and showed that the dynamic trunk motion could be an effective measure to differentiate between normal subjects and LBP patients (McIntyre et al., 1991; Marras et al. 1993,1995).

By the way, the large variation in velocity and acceleration during dynamic movement often decreases the statistical power in distinguishing the performance between normal subjects and patients. In the preliminary study, it was observed that flexion velocity and extension velocity were covariant with ROM ($r=.89$, $r=.93$ respectively) during free dynamic trunk movement. That is, the variation of the ROM increases the variability of velocity or acceleration, and in turn, statistical analysis to differentiate the normal and patient group loses its power. Thus, Kim et al. (1993, 1994) suggested to measure the dynamic variables with controlled ROM by applying Fitts' law (1954) to the trunk. They developed a new experimental protocol and showed that controlling ROM actually reduced the variability of the trunk velocity during oscillatory free dynamic trunk

movement. However, Kim's protocol consists of 22 trials that could be too long for LBP patients who experience a great discomfort during standing and flexion/extension tasks. Therefore, in this study, Kim's protocol was re-examined to reduce the length of testing and, at the same time, maintain the accuracy of the test. Furthermore, this protocol actually tested among LBP patients and control subjects to prove the applicability of the experiment as a diagnostic tool in clinical setting.

Fitts' law

Fitts' law was originally used to quantify the information channel capacity of human arm movement during the tapping tasks between two target points. Fitts hypothesized that movement would take more time if the ratio of movement amplitude to target was higher because more information processing was required. He measured the information processing capacity of the subject in terms of the slope and the intercept of regression line derived from movement time (MT) and index of difficulty (ID).

[MT (movement time) =a + b * ID (index of difficulty)].

The index of difficulty is determined by range of motion (A: amplitude of movement) and target tolerance (W: width of target). That is, $ID = \log_2(2A/W)$.

METHODOLOGY

Statistical analyses to shorten the original protocol

In order to shorten the number of trials in Kim's experiment, a series of analyses were performed. 1) Spearman correlation analysis was performed to re-group the ID conditions based on the degree of association. We could re-group 11 IDs into a fewer number of groups in which dynamic performance parameters (flexion/extension velocity and acceleration) are correlated each other. 2) We also operationally defined a dynamic consistency scale (DCS) which showed the consistency of dynamic performance parameters. This scale measured the distance between dynamic parameters and indicated which ID conditions had more consistent information than the others did. To have unbiased DCS value, dynamic performance parameters were adjusted based on different ROM through Analysis of Covariance, and they were also normalized with respect to their maximum observed values. This process made the dynamic parameters completely independent of ROM and unit free. The DCS was computed according to equation (1).

$$DCS = [(\underline{flex.vel.}^{*} - \underline{ext.vel.})^2 + (\underline{flex.vel.} - \underline{flex.acc.}) + (\underline{flex.vel.} - \underline{ext.acc.})^2 + (\underline{ext.vel.} - \underline{flex.acc.})^2 + (\underline{ext.vel.} - \underline{ext.acc.})^2 + (\underline{flex.acc.} - \underline{ext.acc.})^2]^{\frac{1}{2}} \quad \ldots\ldots (1)$$

*$\underline{flex.vel.}$: *adjusted and normalized flexion velocity*

Validation for LBP patient population

Subject

For the validation of short protocol, ten healthy subjects (five male and five females) whose ages ranged from 23 to 27 (mean=25.2, s.d.=1.2) were used in the study. Their mean height was 177.3 cm (s.d.=6.4) and mean weight was 80.5 kg (s.d.=12.0). Ten LBP patients whose ages ranged from 24 to 40 (mean=27.5, s.d.=6.5) were recruited from several clinics located in Columbus area in Ohio, USA. Their mean height was 171 cm (s.d.=12.2) and mean weight was 79.1(s.d.=14.7). Six of them were males and four of them was female.

Apparatus

The Lumbar Motion Monitor (LMM; Marras, 1992) was used to monitor the time series of ROM data during dynamic trunk movement. LMM is an exoskeleton of the spine that is instrumented to measure 3-D low-back motion. A portable 386 based PC was used to collect and store the data. A target screen was placed in front of the subject to give a real time visual feedback of sagittal trajectory during the oscillatory bending. Trunk movement data were digitized and stored at 60 Hz sampling rate via an analog-digital converter. This data acquisition system is depicted in Figure 1.

Experimental design

Indices of difficulty (IDs) were used as independent measures consisting of various ranges of motion (A) and target tolerances (W). The magnitude of ROM and target size were determined based on previous studies (Fitts, 1954; Langolf et al., 1976; Jagacinski et al., 1980). Average movement time (MT) per cycle was measured as a dependent measure. Peak flexion/extension velocity and acceleration for each cycle were computed as dependent measures. Information processing capacity (1/b), based on Fitts' law, was also used as a dependent measure.

Procedures

After a subject was fitted with the LMM on his back, he/she was briefly instructed how to use the screen feedback in front of them. Then, the subject was told to warm up before the first trial. After a brief practice, the subject was asked to continuously flex and extend the trunk as fast as they can for ten seconds with the screen feedback. If the subject missed the target more than twice, he/she was asked to try it again (Figure 2). The subject was verbally encouraged to perform at their best level of effort during the trials. The order of 22 trials with controlled ROM was randomized.

Hypotheses to test the protocol

Hypotheses were developed to test the new protocol. The null hypothesis are as follows:

1. Information processing capacity or processing time computed from Fitts' protocol is not different between healthy subjects and LBP patients

2. The dynamic parameters such as velocity and acceleration of the back motion are not different between healthy subjects and LBP patients.

RESULTS

A new experimental protocol

The dynamic consistency scales (DCS) are reported and IDs with relatively high correlation (r=.55 and above) are grouped together in Table 1. The lowest possible score of DCS is zero, which signifies the absolute consistency between the dynamic performance parameters. Thus, the DCS and correlation coefficients provided criteria to re-group the IDs and choose the best subsets of 11 IDs. After subsets (3 IDs) were selected, the slope and intercept derived from those subsets were compared to those from 11 IDs by MANOVA in order to ensure the validity and accuracy of the new protocol.

The final selection of the subsets was made based on following order. First, ID conditions with DCS smaller than .40 were selected from each group: ID 1.59^1, 2.33^1, 2.59^1, 2.74^2, 3.00^2, 3.33^3, 3.73^4. (The superscript indicates the group). Second, ID 3.73 was dropped because the target tolerance would become too small to read if the ROM is adjusted for some patients with less than 20 degrees of ROM (Marras et al. 1995).

Third, six subsets with three ID conditions were selected based on the degree of association shown in the correlation coefficients. Regression equations were used to see the difference between 3 IDs and 11 IDs in terms of slope and intercept. The results were tabulated in Table 2.

From the Table 2, none of slope and intercept from 3 ID conditions were found to be significantly different from those in 11 ID conditions even at α=0.1 level. The results gave the experimenter freedom to choose ID conditions among the subsets. Finally, 3 IDs having the most distance each other in terms of ROM were selected: **ID 1.59, ID 2.74, and ID 3.33.**

Final adjustment for LBP patients

One limitation in using this new 3 ID condition can be a restricted ROM among some healthy subjects and low-back patients who couldn't bend any more than 20 degrees. So, ANOVA was used to see whether or not adjusting ROM and target tolerance within the same ID condition could affect the movement time, and we found no significant effect of ROM and target even at α=0.05. Based on this result, the ROM and target tolerance were adjusted if it is necessary to accommodate low-back patients with physical limitation. In this way, a full range of motion of subjects can be measured without exceeding the subject's physical capability. The final clinical protocol with adjusted ROM (A) and target tolerance (W) are tabulated in Table 3.

Protocol testing

The newly designed protocol was tested to actual subjects including ten healthy subjects and ten LBP patients. The hypotheses were tested through statistical analyses. Descriptive statistics of information processing capacity and the test results (ANOVA) are tabulated in Table 4 and Table 5. Furthermore, descriptive statistics and the results of hypothesis test of dynamic parameters are also tabulated in Table 6 and Table 7. The mean value of information processing capacity indicated the increase in among LBP patients. However, it did not show a significant difference between two groups due to a large standard deviation. On the other hand, the dynamic parameter did show a significant difference between two groups in ANOVA test.

DISCUSSION

In this study, the experimental protocol (Kim et al., 1993; 1994) was re-designed for patient population and tested to ensure the validity of the test. First, the short length of the protocol did not exceed the physical ability of LBP patients in terms of endurance and pain tolerance. No patients reported a severe physical pain during and after the test although the dynamic trunk motion increased the level of discomfort among LBP patients. Second, the information processing capacity of dynamic controlled movement could be quantitatively evaluated based on Fitts' law in terms of bits/second, which added a new dimension in the study of human motor control or coordination. Although no significant differences were found between healthy subjects and LBP patients in this test, it showed a trend such that the patient's mean information processing capacity was greater than healthy subject's. This difference might have become greater if we had recruited LBP patients with neurological signs that had been excluded in this study. Therefore, further investigation is necessary to fully understand the utility of this experimental protocol and information processing capacity to evaluate the LBP patients with neurological problems, often influence the control capability of the LBP patients. Third, the dynamic parameters showed its effectiveness to differentiate the dynamic trunk function between healthy subjects and LBP patients under the controlled ROM condition. Dynamic parameters have been effective tools to identify the functional deficiency of musculoskeletal system of the trunk under the self-selected ROM condition. Therefore, it would be interesting if we can compare the different dynamic responses under two different ROM conditions, which may reveal the unique dynamic characteristics caused by the motor control requirement during dynamic trunk motion.

In conclusion, this paradigm provided a quantitative method assessing the motor control capability of coordination of the trunk muscle for the first time. Since the quantification of coordination of trunk muscle has been an important issue in physical therapy or rehabilitation, this finding may introduces a new way of quantifying coordination capability of the trunk among LBP patients. Furthermore, this study showed that this short protocol could be applied to evaluate LBP patients without causing any severe pain due to excessive exertions or long standing which have been major obstacles in functional testing among LBP patients.

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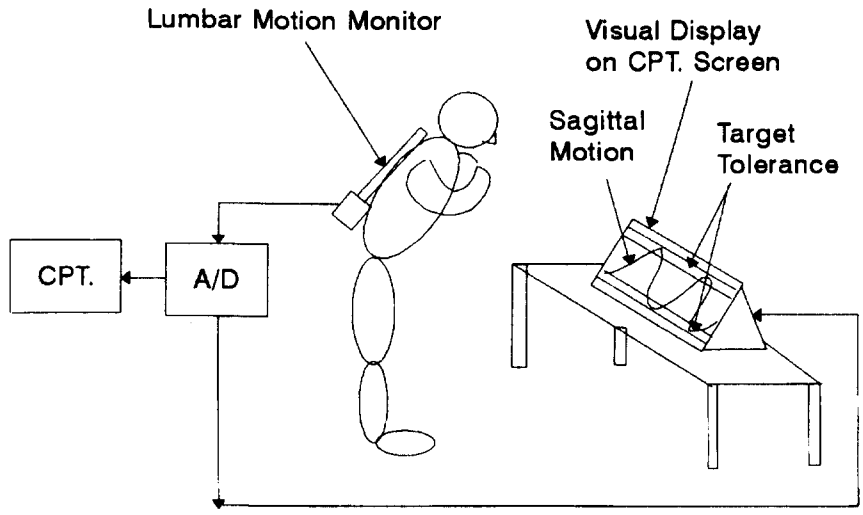

Figure 1
Data acquisition system

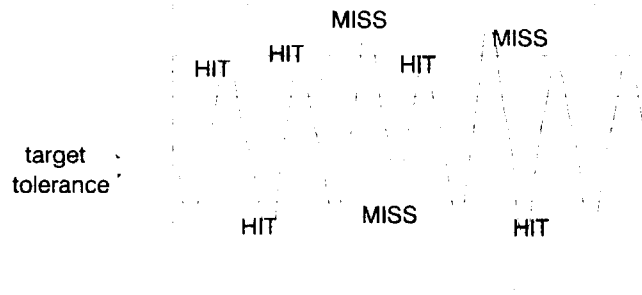

Figure 2
Example of hitting and missing the target on the feedback screen

Table 1
Indices of difficulties with ROM and target tolerance, and
Dynamic consistency scale (DCS) of dynamic performance

ID	trial	ROM (deg.)	target (deg.)	DCS mean±s.d.
1.32[1]	1,2	10&15	8&12	.42±.22
1.59[1]	3,4	10&15	6&9	.32±.13
2.00[1]	5,6	15&20	7.5&10	.44±.22
2.33[1]	7,8	10&20	4&8	.30±.16
2.59[1]	9,10	15&30	5&10	.29±.17
2.74[2]	11,12	20&30	6&9	.35±.14
3.00[2]	13,14	30&40	7.5&10	.31±.13
3.33[3]	15,16	20&40	4&8	.27±.11
3.73[4]	17,18	30&40	4.5&6	.33±.14
3.91[4]	19,20	30&40	4&5.3	.40±.15
4.32[4]	21,22	30&40	3&4	.44±.16

1,2,3,4: groups correlated with each other

Table 2
Comparison between 11 IDs and 3 IDs by MANOVA

3 ID conditions	Wilks' Lamda stat. (Pr>F) 3 IDs vs. 11 IDs
1.59, 2.74, 3.33	.2234
1.59, 3.00, 3.33	.3855
2.33, 2.74, 3.33	.2324
2.33, 3.00, 3.33	.1173
2.59, 2.74, 3.33	.7946
2.59, 3.00, 3.33	.3959

Table 3
Adjusted movement amplitude (A) and target tolerance (W) for different maximum ROM

Fitts condition		Maximum ROM (degree)									
		20-25		25-30		30-35		35-40		>=40	
trial	ID	A	W	A	W	A	W	A	W	A	W
1	1.59	10	6	10	6	10	6	10	6	10	6
2	1.59	15	9	15	9	15	9	15	9	15	9
3	2.74	15	4.5	15	4.5	20	6	20	6	20	6
4	2.74	20	6	20	6	25	7.5	25	7.5	30	6
5	3.33	15	3	20	4	25	5	30	6	35	7
6	3.33	20	4	25	5	30	6	35	7	40	8

A: amplitude of movement: ROM , W: width of target tolerance

Table 4

slope, intercept and Information processing capacity

	normal subjects		LBP patients	
dependent variable	avg	std	avg	std
slope	0.35	0.18	0.30	0.16
intercept (sec)	0.37	0.23	0.88	0.59
inf. pro. cap.(bit/sec)	3.43	1.29	4.22	1.80

Table 5

ANOVA result of information processing capacity and intercept

dependent variable	source	DF	F	Pr>F
inf. pro. cap. (bit/sec)	group	1	0.57	0.4593
intercept	group	1	5.19	0.0351*

* significant at $p<0.05$

Table 6

Descriptive statistics of position, velocity, and acceleration of the back.

dynamic perform. parameter	normal			patient		
	avg	std	CV*	avg	std	CV
back velocity	59.46	14.41	24.23	46.94	12.29	26.18
back acceleration	372.84	120.55	32.33	273.18	132.61	48.54

* CV=coefficient of variation [(std/mean)x100%]

Table 7

Results of ANOVA with kinematic variables of the back.

dynamic performance parameter	source	DF	F	Pr>F
back velocity	group	1	4.37	0.0511*
back acceleration	group	1	3.09	0.0957*

*significant at $p<0.1$