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Dynamic Low Back Functional Motion Capacity Evaluation

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Most current functional capacity evaluations focus on range of motion and strength as measures of wellness. The goal of this study was to evaluate the dynamic functional motion capacity of controls (those without low back pain) and low back pain patients in the three cardinal planes of the body. The hypothesis was that injury would not only affect sagittal motion but also lateral and twisting motion that would load the spine in a different manner. Twenty-six age and gender matched controls and low back pain patients were tested. Trunk motion parameters of range of motion (ROM), velocity, and acceleration were measured in all three planes of the body as subjects performed three separate tasks eliciting motion in each of the three cardinal planes of the body. Controls exhibited significantly higher performance than low back pain patients in all three planes of the body for velocity and acceleration but not ROM. Single parameter discriminant function models indicated that the velocity and acceleration motion parameters distinguished between LBP patients and the control group more effectively than ROM in the cardinal planes. Multiple parameter discriminant function demonstrated that coupled motion models further increased the ability to distinguish between the control and patient groups. These results provide insight into new methods of evaluating functional capacity using velocity, acceleration, and coupling which may provide valuable information in determining the recovery of a patient.

KEY WORDS: dynamic functional motion capacity; low back pain; trunk measurement.

INTRODUCTION

The occurrence of low back pain has been a health concern for decades (1, 2). Nearly 90% of low back pain patients recover within 2–8 weeks regardless of treatment (3). However, the recurrence of low back pain within 2 years of the first episode may be as high as 85% (4). Riihimaki and colleagues (1994) have found that previous history of low back pain increased the risk of LBP fourfold. It is

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postulated that this increased risk of injury may be due to early release from treatment without adequate physiological recovery. Thus, one may argue that we do not have a realistic understanding of the recovery process or the knowledge to evaluate when one may successfully return to work.

Functional capacity testing is often used to indicate readiness to return to work after a low back injury. Functional capacity evaluations consist predominantly of range of motion (ROM), strength testing (6–8), and simulation of specific job tasks (9). However, recent studies have shown that ROM and strength tests do not distinguish between those with low back pain and those without (10, 11). Klein and associates (12) found that isometric strength and mobility could not be used to identify individuals with low LBP. Mandell *et al.* (13) found no difference between patients and postal workers in isometric strength, isokinetic strength, or ROM. The simulation of job tasks evaluates the worker's abilities to perform the strength, endurance, coordination, and pace requirements of the job (9). However, accurate job simulation may be difficult to achieve in a clinical environment. Thus, it is theorized that functional capacity evaluations incorporating strength, ROM, and job simulation may not adequately evaluate readiness to return to work.

Marras and Wongsam (1986) found that sagittal velocity was more effective at distinguishing between controls and low back pain patients than sagittal ROM. However, trunk velocity is not evaluated in functional capacity tests (6). Marras and colleagues (16) have found that during the rehabilitation process the patient's sagittal plane ROM recovered to within one standard deviation of the control group adjusted for age and gender prior to velocity returning to within one standard deviation of the controls. In addition, these researchers found that velocity adjusted for age and gender was within one standard deviation of the control group before acceleration was within one standard deviation of the control group. Thus, ROM recovered to within one standard deviation of the controls first followed by velocity recovery and finally acceleration. The velocity and acceleration capabilities of patients which have been neglected in current functional capacity evaluations may provide valuable information in determining true recovery and successful return to work.

The functional capacity performance of the patients may be influenced by which spinal structures are injured. The spine is composed of vertebral bodies, discs, facets, ligaments, and muscles. Each component plays a role in creating motion in all three planes of the body as well as supporting the spine in compressive, shear, and torsional loading. Injuries to different components may result in impairment of motion in one plane or in some combination of all three planes of the body. In addition, several researchers have shown that injury affects coupled motion. Panjabi and colleagues (1989) found that coupled motion in human cadaver spines changed as a function of the lumbar vertebral level. Pearcy and Tebrewal (1984) using radiographs of the normal lumbar spine also found that coupling was a function of spinal level. Oxland and associates (1992) found that injury to the intervertebral disc significantly increased bending under application of axial torque in cadaver spines. These studies show that coupling is a function of spinal level and that some types of spinal injuries affect coupling. It is difficult to evaluate how considering the influence of musculature in evaluating the thoracolumbar region would affect the cadaver results. It is theorized from the literature, that injury might influence

coupled trunk motion *in vivo* and that quantification of this motion may provide vital information for trunk functional capacity evaluations. However, using current functional capacity tests these types of loading conditions and motions would not even be evaluated.

Since activities of daily living as well as workplace activities may require trunk motion in all three planes of the body, it is hypothesized that functional capacity testing should incorporate evaluation of all three planes of the body. Therefore, the goal of this study was to develop and implement a test that elicits maximum functional motion capacity in the three cardinal planes of the body. The second goal is to quantify differences in an asymptomatic control group and a LBP patient group and determine which motion components (ROM, velocity, and acceleration) distinguish between the two groups best as a function of the cardinal plane tasks.

METHODS

Approach

It has been shown that velocity and acceleration distinguish between an asymptomatic control group and LBP patients in the sagittal plane, thus the objective of this study was to determine whether or not similar results occur in the tasks that require primarily frontal and transverse plane motion. Since trunk motion is three-dimensional, it is theorized that differences in motion parameters due to low back pain would occur in all three planes. The goal of this study was to elicit a maximum voluntary motion in each plane of the body and measure ROM, velocity, and acceleration in all three planes. The experimental tasks were designed to elicit motion in a single plane. However, according to Twomey and Taylor (20) trunk motion rarely occurs in a single plane. These authors also state that there is generally some coupled movement. White and Panjabi (21) have defined motion in two categories main motion and coupled motion as a function of the axis about which force is applied. Applying White and Panjabi's definition of motion in the current study, main motion is in the same plane as the maximum voluntary motion and coupled motion is defined as motion that occurs in the other two planes of the body. Specifically, during lateral bending coupling is defined as motion in the sagittal and transverse planes of the body and the main motion is in the frontal plane. During sagittal bending, the main motion is in the sagittal plane with coupled motion defined as frontal and transverse plane motion. Finally during twisting tasks, the main motion is in the transverse plane and coupled motion is defined as motion in the frontal and sagittal planes.

Subjects

A group of 26 controls with no history of low back pain volunteered for the study. The control subjects ranged in age from 20 to 60. Twenty-six low back pain patients were gender and age matched within the decade to the controls for a total of 52

Table I. Age and Gender Breakdown of Both Controls and LBP Groups

Age	Control group			LBP group		
	Men	Women	Mean (std.)	Men	Women	Mean (std.)
20s	3	3	26.8 (1.2)	3	3	24.8 (2.9)
30s	7	2	34.2 (2.9)	7	2	35.8 (2.2)
40s	4	2	43.7 (2.1)	4	2	43.7 (2.2)
50s	2	2	52 (3.3)	2	2	53.7 (3.8)
60s	1	0	60[a]	1	0	60[a]
Mean (std.)	17	9	38.5 (10.0)	17	9	38.8 (10.7)

[a]Only one subject therefore no standard deviation was calculated.

subjects in the study. The low back pain patients were visiting a secondary referral physician at the time of testing. The patients were in one of seven categories based on either anatomical classification, pain location corresponding to the Quebec Task force study, or screening during physical examination (22). The categories included: herniated lumbar disc, spinal stenosis, localized low back pain (Quebec 1), low back pain with proximal radiation (Quebec 2), low back pain with distal radiation (Quebec 3), postoperative patients with pain (Quebec 9.2), and nonorganic patients. The nonorganic classification was based on five categories during the physical examination including: superficial tenderness, overreaction, regionalization of symptoms, variation in examination with distraction, and simulation maneuvers. The patients with three out five positive signs upon examination were classified as nonorganic. The number of patients from each category were: five from HNP, one spinal stenosis patient, four from Quebec 1, two Quebec 2 patients, four Quebec 3 patients, seven from Quebec 9.2 and three nonorganic patients. Table I shows the age and gender break down for both the control group and the patient group. Anthropometric data were collected for all subjects. Descriptive statistics of the mean (standard deviation) for both the controls and patients are shown in Table II.

Experimental Design

There were two independent variables in the study. First a group variable defined as either controls (those without low back pain) or low back pain patients was considered. The second independent variable was the plane of motion either

Table II. Means and Standard Deviations of Anthropometric Measures for Both Controls and Low Back Pain Patient Populations

Anthropometric measure	Controls	LBP patients
Standing height	170.5 (8.6)	172.9 (10.5)
Weight	174.1 (35.5)	172.0 (38.9)
Trunk length	49.9 (4.3)	51.8 (4.3)
Trunk breadth	31.7 (4.5)	31.2 (4.1)
Trunk depth	24.2 (5.2)	23.7 (4.9)

sagittal, frontal, or transverse. Each plane of motion was a separate task and the order of the three motion tasks were completely randomized.

The nine trunk motion characteristics (dependent variables) were measured for each of the three tasks. These motion characteristics include (1) range of motion (ROM) in the frontal plane, (2) peak velocity in the frontal plane, (3) peak acceleration in the frontal plane, (4) ROM in the sagittal plane, (5) peak velocity in the sagittal plane, (6) peak acceleration in the sagittal plane, (7) ROM in the transverse plane, (8) peak velocity in the transverse plane, and (9) peak acceleration in the transverse plane.

Apparatus

The lumbar motion monitor (LMM) was used to measure trunk motion in all three planes of the body. The LMM was developed in the Biodynamics Laboratory and is an exoskeleton of the spine. It was calibrated on a three-dimensional reference frame in the three cardinal planes. A regression model was developed for each plane with R^{**2} values of 0.978, 0.976, and 0.983 for sagittal, frontal, and transverse planes, respectively. A detailed description of the calibration study may be found in Marras *et al.* (23). The LMM measures instantaneous changes in the position of the thoracolumbar region of the spine. It is attached to two pieces of molded orthoplast which anchor the LMM to the hips and shoulders. The signal from the LMM was sent via hard wire to the analogue-to-digital converter board, resident on a 386 microcomputer. The data collection rate was 60 Hz. The digitized signal was stored in the microcomputer for further processing.

Procedure

Upon arrival to the testing location the subject's anthropometry was collected. The lumbar motion monitor was placed on the subject. The subject was instructed to warm up for the testing. The subjects were instructed to (1) cross their arms in front of their chests, (2) twist from left to right as fast as you can comfortably in a functional ROM, (3) bend side to side (lateral) as fast as you can comfortably in a functional ROM, and (4) flex and extend your trunk (sagittal) as fast as you can comfortably in a functional ROM, and when extending to the upright posture only extend to your comfortable standing posture (5) the start instruction is "ready set go" and you will be instructed to "relax" at the end. By instructing subjects to extend only to their upright standing posture, we are measuring their flexing capability with minimal trunk extension. Instructions 2, 3, and 4 were completely randomized. Eight seconds of data were collect for the control group and 12–14 seconds were collected for the low back pain patient group.

Data Analysis

Custom software developed in the Biodynamics Laboratory converted the electrical voltages from the LMM into position, velocity, and acceleration. The software

program graphically displays trunk position in each plane of the body and allows one to choose which plane as well as the specific part of the data to analyze. The main plane of motion was analyzed from minimum to maximum position for each cycle of motion. The accessory planes of motion were also analyzed in the same section. The first four cycles of motion were measured and averaged, any extra cycles were discarded. The analysis programs determined the average ROM, average peak velocity, and average peak acceleration in the main plane of motion as well as in the coupled planes of motion for the four cycles. The process was completed for the three main plane conditions.

The nine dependent measures were input into a database for statistical analyses. MANOVA tests were performed as a function of the plane of motion with follow up Bonferroni *T*-tests to determine whether or not there was a significant difference between the control group and the LBP patients for each plane. Discriminant function analyses were performed for each dependent measure separately to show how well each individual motion parameter predicted the distinction between the two groups. Finally, multiple variable discriminant function models were developed to distinguish between patients and controls as a function of task.

RESULTS

The MANOVA results showed a significant difference between the control group and the patient group for all three planes of the body. The MANOVA Wilks' Lamnda results indicating a difference between controls and patients had *p*-values of 0.0001 for all three planes of the body. Table III has indicators for which motion parameters had significant differences in the Bonferroni *T*-test at the 0.05 significance level. The descriptive statistics show that the controls have higher functional capacity in the sagittal as well as frontal and transverse planes when compared to patients. The table shows that in the frontal plane task, there was not a significant difference between controls and low back pain patients in the frontal ROM nor was there significant ROM difference in the coupled motions. The controls had significantly higher velocity and acceleration in the frontal plane as well as in both coupled planes of motion during the frontal plane task. In the sagittal plane task, the control group had significantly higher sagittal velocity and acceleration. Controls also had significantly more coupled frontal motion (ROM, velocity, acceleration) than patients during the sagittal task. During the transverse plane tasks, controls had significantly more ROM in the transverse and sagittal planes as well as significantly higher velocity and acceleration in all three planes.

Discriminant function analyses were performed for each dependent measure as a function of task. Discriminant function analysis indicates how well the dependent measure can predict the group thus discriminant function is analogous to regression analysis only discriminant function is for discrete groups (24). The cross-validation error rate for predicting the distinction between the controls and the low back pain patients are listed in Table IV as a function of task and motion parameter. Cross-validation classifies each observation in the dataset using the discriminant function computed from the other observations in the dataset, excluding

Table III. Descriptive Means (Standard Deviations) and Indicator of Significant Difference for Bonferroni *T*-Test, Significance at 0.05[a]

Motion parameter	Frontal plane task		Sagittal plane task		Transverse plane task	
	Control (26)	Patient (26)	Control (26)	Patients (26)	Control (26)	Patients (26)
Frontal plane						
Lateral range	**39.9**	**37.1**	4.6	2.6[b]	10.1	9.1
	(9.7)	**(13.6)**	(2.9)	(1.9)	(6.6)	(5.8)
Lateral velocity	**118.3**	**56.2[b]**	18.5	5.6[b]	41.5	22.5[b]
	(37.9)	**(30.4)**	(12.9)	(4.3)	(23.8)	(14.6)
Lateral acceleration	**554**	**172[b]**	128.6	26.9[b]	304.8	132.4[b]
	(236)	**(123)**	(92.7)	(17.2)	(163.2)	(102.7)
Sagittal plane						
Sagittal range	5.4	4.6	**41.2**	**31.6[b]**	11.2	6.6[b]
	(2.3)	(2.8)	**(14.5)**	**(10.1)**	(5.6)	(3.8)
Sagittal velocity	25.3	12.2[b]	**122.9**	**50.4[b]**	53.6	21.4[b]
	(11.6)	(9.8)	**(44.3)**	**(22.7)**	(21.5)	(17.5)
Sagittal acceleration	182.1	66.0[b]	**642.5**	**175.2[b]**	373.3	131.0[b]
	(94.4)	(56.0)	**(376.6)**	**(103.8)**	(140.5)	(131.9)
Transverse plane						
Transverse range	7.6	6.5	2.6	2.4	**47.4**	32.5[b]
	(5.2)	(5.4)	(1.8)	(2.6)	**(14.7)**	**(14.2)**
Transverse velocity	29.8	14.7[b]	9.9	6.9	**169.3**	**74.4[b]**
	(20.4)	(11.8)	(7.5)	(11.3)	**(62.6)**	**(55.9)**
Transverse acceleration	197.0	75.0[b]	66.0	38.3	**1021.6**	**403.9[b]**
	(143.6)	(46.7)	(40.8)	(63.7)	**(454.6)**	**(36[illegible]7)**

[a]The bold type represents the primary plane results.
[b]Significant difference between control group and patient group on Bonferroni *T*-test.

the observation being classified (25). The cross-validation error rate provides a better prediction of how future datasets will classify than resubstitution error-rates. In all three planes, the ROM parameter misclassified the most in predicting the control group and LBP patient group. In the frontal plane, the lateral acceleration performed best at discriminating the two groups. The sagittal plane task results

Table IV. Cross-Validation Error Rates for Single Parameter Models to Predict the Distinction Between Controls and LBP Patients[a]

Motion parameter	Frontal task error rate	Sagittal task error rate	Transverse task error rate
Frontal plane			
Lateral ROM	**42%**	34%	56%
Lateral velocity	**21%**	25%	40%
Lateral acceleration	**11%**	17%	29%
Sagittal plane			
Sagittal ROM	36%	**44%**	34%
Sagittal velocity	23%	**11%**	13%
Sagittal acceleration	19%	**13%**	13%
Transverse plane			
Transverse ROM	46%	48%	**27%**
Transverse velocity	31%	36%	**19%**
Transverse acceleration	25%	34%	**19%**

[a]Bold type represents the main plane results.

show that the sagittal velocity parameter was most effective at distinguishing the two groups. In the transverse plane task, the velocity and acceleration were the two main plane variables which performed equally well at discriminating the different groups, however, the coupled motion parameter of sagittal acceleration discriminated the two groups the best. These results show that velocity and acceleration motion parameters discriminate the controls and the low back pain patients more effectively than ROM parameters in all three planes of the body. Theoretically, it may be possible to have impairment in one plane and not in another depending on which components of the spine are injured. Therefore, it is important to evaluate dynamic functional motion capability in the three cardinal planes of the body. In addition, coupled motion also discriminated between controls and low back pain patients.

Stepwise discriminant function analyses were performed on each of the three cardinal plane tasks. The stepwise models were evaluated to determine how well each one discriminated between controls and low back pain patients for each experimental task. In addition to the stepwise model, a completely saturated model (all variables), an acceleration model (frontal plane acceleration, sagittal plane acceleration, and transverse plane acceleration), a velocity model, a ROM model, a main plane of motion model (sagittal ROM, sagittal velocity, and sagittal acceleration for the sagittal plane task), as well as several coupled motion models were evaluated for each of the three cardinal plane tasks. Table V lists the motion parameters that were incorporated in the final models for the three experimental tasks. The final models were chosen based on their cross-validation error rates. In the frontal plane task, a model containing frontal acceleration alone discriminated between the control group and the patient group most effectively. In the sagittal plane, coupled motion from the frontal plane appears in the final model as well as main sagittal ROM and sagittal velocity. The best model for discriminating controls and patients during the transverse plane tasks contained all the transverse plane motion variables (ROM, velocity, acceleration) as well as coupled sagittal acceleration. Discriminant function cross-validation results for each of these models are shown in Table VI. The results show that the sagittal model performed the best with a cross-validation error rate of 6% followed by the transverse model and the frontal planes model performance. Thus combinations of motion parameters discriminate between controls and patients more effectively than single plane models in the sagittal and transverse planes.

Table V. Motion Parameters that Were in the Final Model to Predict the Distinction Between Controls and LBP Patients for Each Experimental Task

	Frontal plane task	Sagittal plane task	Transverse plane task
Motion parameter	Lateral acceleration	Sagittal ROM Sagittal velocity Lateral acceleration	Transverse ROM Transverse velocity Transverse acceleration Sagittal acceleration

Table VI. Discriminant Function Cross-Validation Results for Each of the Three Tasks[a]

	Frontal plane model		Sagittal plane model		Transverse plane model	
	Control	Patient	Control	Patient	Control	Patient
Control (26)	**22**	4	**23**	3	**23**	3
	85%	15%	**88%**	11%	**88%**	11%
Patient (26)	2	**24**	0	**26**	3	**23**
	8%	**92%**	0%	**100%**	11%	**88%**
Error rate	11%		6%		11%	

[a]The bold type indicates the boxes of correct classification for each model.

DISCUSSION

The results show that velocity and acceleration motion parameters provide valuable information in discriminating between the control group and the low back pain patient group. The results of this study are in agreement with previous research (14–16) indicating that velocity distinguishes between controls and patients more effectively than ROM. Furthermore, this investigation shows that this discriminating capability also holds for main motions in the frontal and transverse planes. In addition, final models of the sagittal and transverse planes incorporated coupled motions. Therefore, it is important to evaluate ROM, velocity, and acceleration in the main plane of motion for all three cardinal planes of the body as well as coupled motion in the accessory planes.

The amount of coupling decreased in patients compared to controls. This results initially appears to be in contradiction with the results of Oxland and colleagues (19) who found that disc injury increased with coupled lateral rotation under axial torque loading. However, Oxland and colleagues performed their study with cadavers thus neuromuscular control was not considered. It is hypothesized that the reduction in coupling found in low back pain patients may be caused by an increase in coactivity of the muscles in low back pain patients or inappropriate activation patterns.

Previous research in the Biodynamics Laboratory (15, 16) has shown that we can predict two categories of controls and low back pain patients using discriminant function with an 11% test set error rate. The protocol for the previous functional evaluation elicited maximum sagittal motion while controlling twisting position. Using White and Panjabi's definition of motion, all the tasks in the previous protocol elicit main sagittal motion, coupled lateral motion, and coupled twisting motion. Therefore, only the sagittal plane task with a cross-validation error rate of 6% is comparable to the previous protocol. The previous test protocol required a higher level of motor control than the current cardinal plane test protocol required, however, the previous protocol does not include dynamic functional evaluation of main motion in the transverse or frontal planes of the body.

From a biomechanical point of view, main motion in each of the three planes of the body is generated and restricted by different components of the trunk. The rectus abdominus and erector spinae muscles act in flexing and extending the trunk

to create sagittal plane motion. The supraspinous and interspinous ligament restrict sagittal flexion (26) whereas extension is restricted by the anterior longitudinal ligament (27, 28). Lateral flexion of the spine is generated through activation of the rectus abdonimus, external obliques, internal obliques, erector spinae, quadratus lumborum, and multifidus muscles (29). Lateral flexion is restricted by the contralateral transverse ligament, ligamentum flavum, and the capsular ligament (28). Transverse plane motion is generated by activation of the latissumus dorsi, internal and external oblique, and quadratus lumborum muscles (30) and restricted by the capsular ligament (28), as well as the facets (21). The disc acts to restrict lateral coupled motion during applied torque, according to Oxland and associates. Since motion is generated and restricted by different components of the spine as a function of the plane of motion it is theorized that the cardinal plane protocol provides a more thorough understanding of trunk functional motion capacity and readiness to return to work than the previous protocol. It is not our theory that this test protocol will provide information as to which tissue is actually limiting motion (ROM. velocity, or acceleration) but that the test will provide a more exhaustive evaluation than current functional capacity evaluations.

Application

These results demonstrated the differences that occur in motion components in all three planes of the body. Therefore, in evaluating functional capacity of low back pain patients, it is suggested that frontal and transverse plane performance could be evaluated in addition to sagittal plane performance. Also, the range of motion evaluations that have been done previously should be performed dynamically and the velocity and acceleration measures should be incorporated into functional capacity evaluations. By neglecting to evaluate the dynamic components of functional capacity one may be missing important information in evaluating recovery.

An important step of the recovery process is returning to work. It is theorized that a proper evaluation for returning a low back pain patient to work would incorporated both a functional capacity evaluation as well as an ergonomic evaluation of the risk factors due to job. Marras *et al.* (31) showed that trunk velocity is one of the critical risk factors in determining the probability of being at high for developing low back pain due to the job. It is hypothesized that jobs with low weight levels which may be considered light duty may have a high trunk velocity that could put the worker at risk of reinjury. One can evaluate the trunk velocity of the job as well perform functional capacity evaluations on standardized tasks with the LMM. Future longitudinal research is needed to determine the probability of reinjury given a specific dynamic functional capacity and a specific exposure level. The probability of injury could be based on the ratio of capacity/job for each motion parameter.

Limitation

The first limitation of this study is that the results are only applicable when using the lumbar motion monitor and not other triaxial goniometers. Second, the

focus of this investigation was to evaluate the patient's/worker's capacity dynamically which would be an important measure when returning a worker to a job involving light highly repetitive tasks that may require dynamic trunk motion. However, dynamic trunk motion is not the only occupational risk factor for developing LBP, epidemiological studies indicate the occupational risk factors also include: prolonged sitting, driving vehicles, vibration, as well as psychological issues which are not evaluated by the LMM. Further research is necessary to develop methods of evaluation for these other occupational risk factors.

CONCLUSION

1. Significant differences occur between the control group and low back pain patients in all three planes of the body therefore measuring all three planes of the body provides a more thorough understanding of dynamic functional motion capacity of patients.

2. Main motion components of velocity and acceleration distinguish between patients and controls more effectively than main ROM in all three planes of the body.

3. Coupled motion in the sagittal plane during transverse plane motion and coupled lateral motion during sagittal plane motion contributed to the discriminating power between patients and controls.

4. Dynamic components of velocity and acceleration contribute to models which discriminate well between patients and controls these measures should be incorporated into functional motion capacity evaluations.

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