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Lumbopelvic movement control in contemporary dancers: A multiple case study.

Running Head: Lumbopelvic movement control in dancers

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ABSTRACT

The purpose of this study was to describe and evaluate lumbopelvic movement control in professional dancers and to discuss its potential meaning for dance technique, performance and dance-related injuries. Lumbopelvic movement control was approached from a perspective of functional testing by adapting existing lumbopelvic movement control tests for dance related tasks. Six healthy professional dancers performed a total of 72 balances in three different forms. Following biomechanical variables were determined using a 3D motion analysis system: 1) joint angles of the supporting leg and pelvis, 2) hip joint moments, and 3) lateral shift of pelvis. Results indicated that altered lumbopelvic movement control was common: most often asymmetric pelvis control was observed, and it was typically found in lateral shift of the pelvis. Additionally, increased lateral shift was related to increased frontal plane moments in the hip joint. These findings suggest that lumbopelvic movement control should be evaluated also in highly skilled professional dancers and that health care intervention may be required to promote healthy dancing, dance performance and ethical dance teaching. In addition, the study shows that 3D motion analysis can be used to assess movement control during activities relevant for a specific sport or movement task.

Key Words: biomechanics, dance, camera-based motion analysis, motor control

INTRODUCTION

Dance injuries are often repetitive motion injuries that occur especially in the lower limb, hip and spine.[1-6] Etiology of dance injuries ranges from factors such as previous injuries, laxity of joints, faulty technique, choreography, and dancing style to name a few.[7] Additionally, altered lumbopelvic movement is stated to be related to pain and injuries in dancers.[8] More specifically, previous dance-related research suggests that lumbopelvic movement control tests can be associated with an increased risk of developing lower extremities or lumbar spine injuries.[8] Thus, in order to reduce and prevent repetitive motion injuries in dancers, it is useful to investigate and describe functional movement patterns that relate to the actual praxis. This can give essential information for dance instructors and teachers on possibly harmful exercising habits and movements that can lead into injuries.[9,10]

Optimal lumbopelvic stability and control is a function of form closure (i.e. joint anatomy), force closure (i.e. additional compressive forces acting across the joints) and neuromotor control. Impairment of any of these mechanisms can result in pain, instability, altered lumbopelvic kinematics, and changes in muscle strength and motor control.[11] It has been stated that the altered movement control is indicative for both people with symptoms and those who have not reported lumbar spine pain. Thus, when identifying a dysfunction of the musculoskeletal system early, it may be possible to address these dysfunctions to avoid pathologies and pain as well as minimize the risk of irreversible structural changes.[12] Tests that examine the control of lumbopelvic movement are often performed with an active hip movement.[13-16] As an example, an optimal movement control performance is obtained when pelvis and lumbar spine maintain neutral position in horizontal and frontal planes, sacrum remains in slight anterior tilt while innominate rotates posteriorly while lifting gesture leg (i.e. flexing both hip and knee).[12,16] Thus, the neutral position of the lumbar spine should be maintained, rotation controlled and pelvis stability performed in synergy. Hence, anterior rotation suggests failure to stabilize intra-pelvic motion for load transfer and is considered as a non-optimal pattern and may indicate abnormal articular or neuromyofascial function during increased vertical loading through the pelvis.[13]

Tests of lumbopelvic movement control are often performed using simple tasks such as lifting one leg while standing still.[15] These tests may not be challenging enough to reveal difficulties in movement control in highly trained dancers. In addition, they may not represent requirements for lumbopelvic control during actual dance praxis. Therefore, the purpose of this case study was to 1) adapt previously used tests of lumbopelvic movement control for dance related tasks using 3D motion analysis, 2) to describe and evaluate lumbopelvic motor control in six cases during typical and 3) to discuss lumbopelvic motor control and its potential meaning for dance technique, performance and dance-related injuries.

MATERIAL AND METHODS

Participants

A total of six professional dancers aged 18–55 years (36.5 mean) participated in the study. The healthy volunteers (men and women) were recruited among Tero Saarinen Company and they had worked as professional dancers approx. 17 years on average. Dancers were coded as P1 to P6. Detailed inclusion and exclusion criteria are in Table 1.

Data collection

Measurements were performed at the motion laboratory of the Department of Applied Physics, University of Eastern Finland. Each dancer participated to one test session (approx. 60–90 min). The participants were informed that their involvement was voluntary and withdrawal at any stage would be possible without further explanation. After a full explanation of the study, and a possibility to ask further questions, written informed consent form was signed. The study (157/2016) was approved by the ethics committee of the Research Ethics Committee of the Northern Savo Hospital District.

Prior to the measurements, the participants completed a medical screening questionnaire before the testing day. The tests were performed on the day of a dance performance (unrelated to the study) or few days (1–3 days) later. To minimize the risk of injury, the participants were given the opportunity to warm-up prior to and after the attachment of the markers used for motion analysis. Rest intervals were allowed during the data recording (approx. for 40 seconds) between the tasks as required. The participants were also given a practice trial before each task to be more familiar with the surface and stepping on the force plate. After completing each task, the participant reported pain via numeric rating scale (NRS; self-reported pain score in integers: 0–10)[17-18] to monitor possible adverse effects.

The test battery started with a static capture (standing in anatomical position) that was followed by dance movements. In this study, we modified single leg tests used as lumbopelvic control tests according to dance-based movements (discussed in detail in analysis). The subjects performed three different forms of balances unshod. Each balance was performed with six continuous and consecutive attempts. The trials that were used for further analysis were those in which the participants' stance leg was completely on the force plate. All the single lower limb exercises were repeated on both legs. Movements were executed both in parallel (i.e. feet directed straight, indicated as P) and in first position (i.e. hip lateral rotation, indicates as LR) of 40–45 degrees of the legs, hands were held at the waist. Thus, 72 balances were performed in total.

The following movements (see Figure 1) were performed with a step on the force plate and executed both in P and LR: 1) *demi plié* and extension of supporting leg with gesture leg in *sur le cou-de-pied*, 2) *demi plié* and extension of the supporting leg with gesture leg in *passé*, and 3) *demi plié* and extension of the supporting leg with gesture leg in *á la seconde*. The selected movements gradually increased range of movement in the gesture leg and complexity of the task.

We performed motion analysis with a six-camera motion analysis system (based on Basler A602f monochrome CMOS cameras and one additional Basler A602fc RGB reference camera) with a sampling rate of 100 Hz. The six A602f cameras were equipped with IR LEDs and IR filters and they were used to capture location of the reflective markers placed on the subjects throughout the movements. The reference camera captured a video, to provide overview of the movements. We used a force platform (OR6-7MA, AMTI Inc.; MA, USA) to record ground reaction forces of the stance foot. A total of 41 individual retro-reflective spherical markers (diameter 18 mm) and four clusters (3 markers each) were attached at specific anatomical locations. We placed markers bilaterally over auriculars lateral sides of acromions, inferior angles in scapulas, elbows, angulus of sternum, posterior and anterior superior iliac spines, greater trochanters, lateral and medial femoral epicondyles, medial and lateral malleoli and 1st and 5th metatarsal bones. In addition, markers were placed over top of the head and 7th cervical spinous process. Clusters of markers were placed bilaterally on thigh and shank. Marker trajectories were reconstructed, and lower body kinematics were calculated using in-house developed custom 3D body model in MATLAB R2014a (Mathworks Inc.; MA, USA) environment. Model enabled visual inspection of 3D motion throughout the movements. Model was fitted to data utilizing state-space approach. Details on the method have been reported earlier.[19] We calculated joint angles according to Vaughan and colleagues.[20] Following parameters were extracted for analysis: 1) joint angles of supporting leg, 2) joint moments, and 3) orientation and location of pelvis. External hip joint moment in frontal plane was calculated as the product of ground reaction force vector and its moment arm in relation to hip joint center in frontal plane. The moments were normalized by body weight to enable comparison between subjects. The repeat trials from each subject were first time normalized and then averaged.

Adverse effects

Two of the participants reported pain during the testing protocol: one during the warm-up (NRS 1) and the other during actual testing: the pain was aggravated in positions of the *á la second* (NRS 1–3 superiorly to trochanters, NRS 3 right groin).

Data analysis

Based on previous research, we selected following three factors to estimate and describe lumbopelvic motor control: 1) anterior tilt, 2) rotation and 3) lateral shift of the pelvis. For lateral shift, side difference and absolute distance for both legs were evaluated. In addition, the selected criteria for altered lumbopelvic motor control (i.e. anterior tilt of pelvis, rotation of pelvis and lateral shift) used in this case study are feasible for dance professionals (by using palpation for example) and they are easy to adapt to actual teaching. For analysis, threshold values (i.e. as centimeter, degree) were set according to previous literature.[14,-16,21] According to Sahrmann[16], test result is indicative of impairment if supporting (i.e. stance) lower limb's hip joint is in adduction or rotation occurs in lumbar spine, pelvis or hip joint. Additionally, lateralization (or lateral shift) of the pelvis during one leg stance is found as a simple test to evaluate movement control and lack of force closure.[21] In a test described by Luomajoki and colleagues[15], lateral movement of the belly button is measured in transition from normal standing to one leg stance. Ideally, the distance of the transfer should be symmetrical between right and left lower limb, and side difference should be less than 2 cm. For Lahtinen-Suopanki and Koho[21], lateralization of the pelvis during one leg stance was evaluated by measuring the lateral transfer of the S1 processus spinosus from normal stance, feet together, to one leg stance: 1.5 cm difference between sides was associated with dysfunction. Based on these previous studies the following cut-off values for impaired lumbopelvic control were chosen for the current study: 1) in side difference of lateral shift ≥ 1.5 cm, 2) in absolute lateral shift ≥7.5 cm, and 3) in anterior tilt of the pelvis during the movement ≥ 2 degrees. In addition, as fourth aspect, rotation of pelvis was compared between the trials done with different support legs.

The aforementioned parameters describing movement pattern in different tasks were taken from the average data during the single leg balance. To quantify lateral shift of pelvis in transition to single leg balance, a modified version of the previously used methods[15,21], was used. In detail, we defined lateral shift as the change in frontal plane distance between center of pressure of ground reaction force and the stance leg hip joint center from the starting position to the position during balance. This reflects lateralization of the hip in the single leg balance and is therefore comparable to the previously used tests but allowed to obtain this measure during dance-related movements.

RESULTS

In general, based on the selected criteria, uncontrolled lumbopelvic movement was common for the participated dancers and asymmetry was prominent. Detailed results are presented in the following as: 1) jointed factors as lateral shift and position of pelvis in movements of *sur le cou-de-pied* and *passé*, 2) lateral shift and moments in all movements.

Results related to lumbopelvic control criteria (i.e. lateral shift, orientation of pelvis) for this study are described in detail in figure 2. In short, the participated dancers had different profiles by which they filled the criteria. For example, one of the dancers (P1) had challenges in all the criteria: 1) in lateral shift (i.e. side difference was apparent in all movement pairs, and in lateral shift distance especially while having the right leg as the stance leg) and in 2) control of pelvis (control of both tilt and rotation of the pelvis while having the right leg as the stance leg). On the contrary, results of P3 showed challenges only in lateral shift (i.e. side difference in all movement pairs and in lateral shift distance while having the left leg as the stance leg) but not in control of pelvis in sagittal and transverse planes. P6 had similar results but in fewer movements. P4 and P5 had minor challenges both in lateral shift and in control of pelvis. In addition, P2 had minor indications of impairment due to large lateral shift and rotation of pelvis while having the left leg as the stance leg. Interestingly, the posture of P2 was in posterior tilt throughout the test based on visual inspection but since only change in pelvis position was quantified by the 3D motion analysis, this indication was not fully reflected in the quantitative results. For the whole study group, most of the indications of uncontrolled movement were found in the amount of lateral shift.

Lateral shift and hip joint moments

Thus, lateral shift was commonly found as stated earlier (see detailed results in table 2). On average, side differences were 2.4 cm absolute values of lateral shift were 8.9 cm for the right side stance and 8.5 cm for the left side stance. Side difference in lateral shift were mostly observed during parallel foot position movements, but indications of uncontrolled movement based on excessive lateral shift (≥7.5 cm) were observed also in movements performed in lateral rotation. When observing the highest and lowest moments (see table 3), results mirrored the results regarding distance of lateral shift. Thus, the longer distance, the higher moment. The amplitude (i.e. position) of the gesture leg did not affect to the moment.

DISCUSSION

The purpose of this case study was to examine lumbopelvic control in professional contemporary dancers while practicing dance-related movements in different balances. The primary findings were that, altered lumbopelvic control was common and most often manifested as limb difference in pelvis lateral shift (i.e. ≥ 1.5 cm). Larger lateral shift of the pelvis was also associated with increased hip joint moment in frontal plane. In detail, altered lumbopelvic control was more commonly found in lateral shift than in control of pelvis tilt or rotation. Thus, the latter suggests that dancer may have a manageable postural control of pelvis, but due to different reasons beyond discussion of this study design, challenges in motor control still exists as indicated by side difference in the amount of lateral shift. For side differences, they were typically found in parallel foot position movements, while excessive lateral shift was found in movements performed in lateral rotation.

Earlier studies used values surpassing 1.5 cm[21] or 2 cm[15] for asymmetry of lateral shift to indicate altered movement control. Our results surpass these values as asymmetry was prominent and side difference 2.4 cm on average, without reported pain. In other previous study[14], the mean lateral shift of the pelvis on the asymptomatic side was 42.85 mm and on the symptomatic side 62.60 mm. On average, the values of lateral shift for the participated dancers were 89.00 mm for the right-side stance and 85.00 mm for the left-side stance. Thus, both side difference and absolute values of later shift well exceed the previously reported values for symptomatic patients. This may be due to larger range of motion of dancers, accessible movement from elsewhere (i.e. compensations), as well as trained and manageable postural control of pelvis to suggest a few. Hence, a future prospective study to investigate whether painless motor control alterations lead into pain and/or injuries is warranted. Investigation if teaching interventions are able to reduce amount of lateral shift and side difference in lateral shift are other suggestions for future studies.

As 3D motion analysis systems has become more common in research and clinical settings, it would be beneficial to develop versatile dance-specific tests for motor control that take advantage of this method. In addition to teaching-based interventions, 3D analysis provides more objective and accurate information of dancer's movement during typical movement performed in dance praxis and can be used to for example to detect even subtle changes in movement patterns as well as improvements due to rehabilitation regimes. Since role of stabilization of pelvis and hip[22-26] and associated delayed muscle activity is common with uncontrolled movement[13] it is advisable to combine EMG with motion analysis when designing tests to be used in research and in clinical practice. Other noteworthy implication to consider for future research is different strategies that the dancers used in this study to decrease frontal plane hip joint moments such as upped body lean in the opposite direction as the lift of the gesture leg. This may have importance especially in off-balances performed in the *seconde* in parallel due to restricting anatomical reasons.

Several study limitations need to be stated. It should be kept in mind that a multiple case study and its results must be approached cautiously. Thus, reader should generalize these findings with caution. In addition, the tasks performed in this study were relatively elementary, and a different study design may give different emphasis on results. The well-known soft-tissue artifact of skin-mounted markers[27] must be taken into account when quantifying joint kinematics. Additionally, thresholds for detecting impairment were set narrowly and could not be set in detail in every parameter (i.e. rotation of pelvis). Importantly, testing was performed on the day of a dance performance or few days later. Hence, choreography and its requirements to movements may have affected performance of the dancers due to fatigue created by the performance. Additionally, other external reasons may exist: such as choreography, and / or even previous injuries that were beyond exclusion criteria and possibly appearing in closed kinetic chain.

PERSPECTIVES

The current case study offers complementary data to previous literature regarding movement control of the stance leg's hip and associated lumbopelvic control. To conclude, altered lumbopelvic movement control was commonly found in professional dancers while performing dance-related movements. The altered movement control and its asymmetry may contribute to alterations in the kinetic chain and may be a risk factor for injury as well as hinder dance performance. Hence, further knowledge on movement control, rehabilitation and prevention, and risk of injury are warranted. In addition, development of feasible strategies to test lumbopelvic movement control and to monitor progression in rehabilitation related to dance practice is vitally important for dance teachers, dancers and clinicians for promotion of both technically sound and ethical dance teaching as well as healthy dancing.

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TABLES

TABLE 1. Inclusion and exclusion criteria.

Inclusion criteria	**Exclusion criteria**
age: 18–55 years	General contraindications:
professional dancer	-acute disease or sickness -acute musculoskeletal injury
	Study design contraindications:
	-joint replacement (i.e. artificial joint) in knee or / and hip -current rehabilitation process for an injury on lower extremities

TABLE 2. Side differences and lateral shift in centimeters in different movements when exceeding cut-off values for indication of abnormal movement control.

Participant	Side difference (cm) ≥ 1.5	Lateral shift (cm) R ≥ 7.5	Lateral shift (cm) L ≥ 7.5
P1	2.2 P-c-d-p 2.7 P-passé 2.4 LR-c-d-p 2.6 LR-passé 2.2 LR-seconde	8.4 P-c-d-p 8.9 P-passé 10.4 LR-c-d-p 9.5 LR-passé 11.5 LR-seconde	8.0 LR-c-d-p 9.3 LR-seconde
P2	2.1 P-c-d-p 1.7 LR-seconde		7.7 LR-c-d-p 7.8 LR-passé 8.0 LR-seconde
P3	3.3 P-c-d-p 2.1 P-passé 4.0 P-seconde 1.5 LR-c-d-p 2.8 LR-passé	7.7 LR-c-d-p	8.3 P-c-d-p 7.8 P-passé 9.2 LR-c-d-p 9.6 LR-passé 8.5 LR-seconde
P4	1.5 P-passé 3.6 P-seconde 2.3 LR-passé 3.5 LR-seconde		7.5 P-seconde 8.0 LR-passé 9.7 LR-seconde
P5	1.8 P-c-d-p 2.0 P-passé 1.8 P-second	8.7 LR-c-d-p 8.1 LR-passé 8.6 LR-seconde	8.7 P-c-d-p 8.5 P-seconde 9.0 LR-c-d-p 9.2 LR-passé 10.0 LR-seconde
P6	1.7 P-c-d-p 3.7 P-passé 1.8 P-seconde	8.2 LR-c-d-p 8.4 LR-passé	7.5 P-c-d-p 8.6 P-passé 9.1 LR-c-d-p 8.8 LR-passé 7.8 LR-seconde

L/R = left or right lower limb as stance limb (indicated in the beginning of the movement code)

P = parallel (indicated in the beginning of the movement code)

LR = lateral rotation (indicated in the beginning of the movement code)

c-d-p = gesture leg held in *sur le cou-de-pied*

passé = gesture leg held in *passé*

seconde = gesture leg held in *á la seconde*

TABLE 3. Average normalized hip joint moments (Nm/kg) and the movements in which the highest and lowest values were observed with their respective values.

Participant	Average, R	Average, L	Highest	Lowest
P1	0.106	0.085	0.127 R-LR-seconde	0.073 L-P-passé
P2	0.074	0.090	0.099 L-LR-c-d-p	0.05 R-P-seconde
P3	0.068	0.093	0.107 L-LR-passé	0.061 R-P-passé
P4	0.079	0.094	0.112 L-LR-seconde	0.064 R-P-seconde
P5	0.081	0.096	0.111 L-LR-seconde	0.062 R-P-passé and R-P-seconde
P6	0.080	0.092	0.097 L-LR-c-d-p	0.067 R-P-seconde

L/R = left or right lower limb as stance limb (indicated in the beginning of the movement code)

P = parallel (indicated in the middle of the movement code)

LR = lateral rotation (indicated in the middle of the movement code)

c-d-p = gesture leg held in *sur le cou-de-pied*

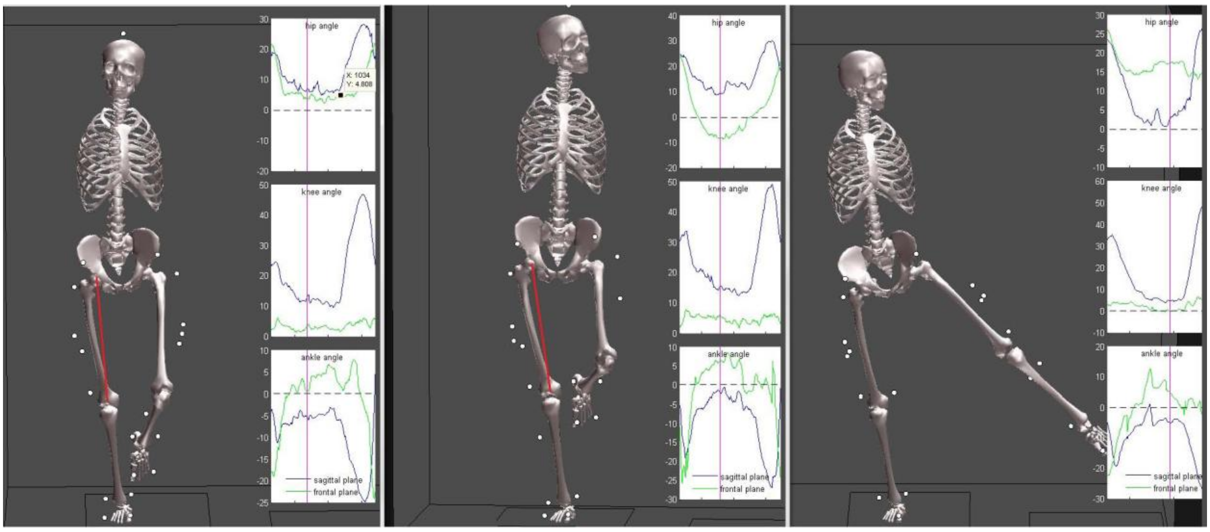
passé = gesture leg held in *passé*

seconde = gesture leg held in *á la seconde*

FIGURE LEGENDS

FIGURE 1. An example of the test movements performed by a subject in parallel position: (starting from the left) *cou-de-pied*, *passé* and *á la seconde*. Joint angles (hip, knee and ankle) are visualized in the right side of the user interphase.

FIGURE 2. Distribution of the different indications of altered lumbopelvic movement within the participants. Results of lumbopelvic movement control in lateral shift (i.e. both side difference and distance) and in control of pelvis (i.e. anterior/posterior tilt, rotation) in movements of *sur le-de-pied* and *passé* (both in parallel and lateral rotation). Movements of *á la seconde* are not included due to anatomical reasons in parallel (i.e. abduction of the hip is normally approximately 30–40 degrees due to bony structures, hence compensations are needed to reach *á la seconde* in parallel position). LS, side = lateral shift, side difference (≥ 1.5 cm); LS, R= lateral shift, distance in right leg stance (≥ 7.5 cm); LS, L = lateral shift, distance in left leg stance (≥ 7.5 cm); PA, R = pelvis, anterior tilt, right leg stance (≥ 2 degrees); PA, L = pelvis, anterior tilt, left leg stance (≥ 2 degrees); PR, R = pelvis, rotation, right leg stance (side difference); PR, L = pelvis, rotation, left leg stance (side difference).


hip angle
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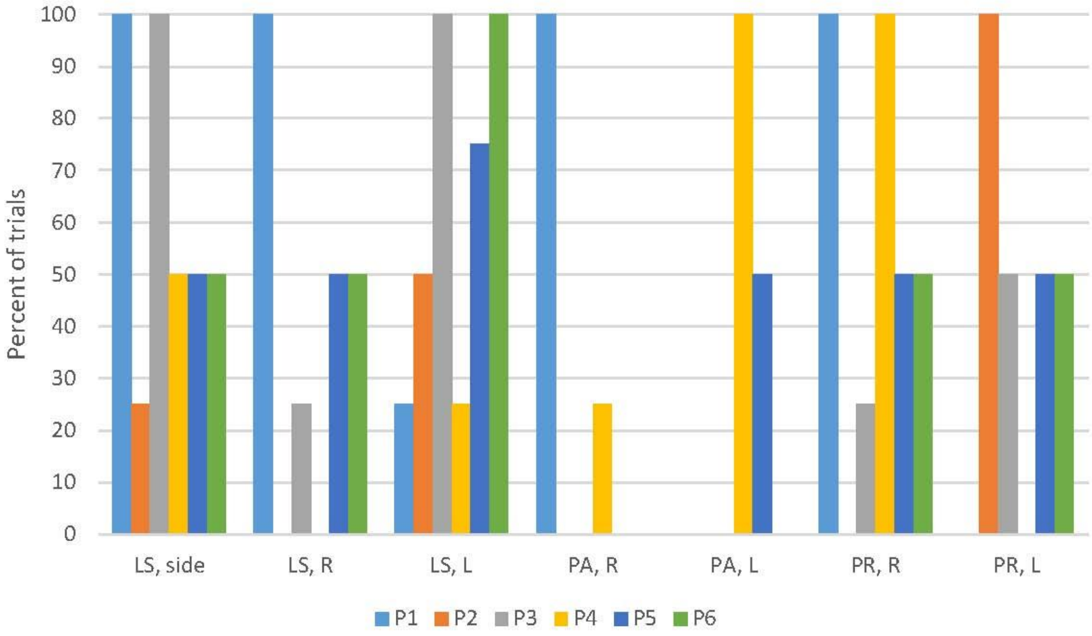
sagittal plane
frontal plane


Percent of trials
0
10
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40
50
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LS, side
LS, R
LS, L
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PR, L
P1
P2
P3
P4
P5
P6