Objective comparison of a sit to stand test to the walk test for the identification of unilateral lameness caused by cranial cruciate ligament disease in dogs

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Abstract

Objective:

The purpose of this study was to evaluate a sit to stand test (STST) with the walk test (WT) for the identification of unilateral cranial cruciate ligament rupture (CCLR) in dogs.

Methods:

Peak vertical force (PVF) and vertical impulse (VI) was measured on a pressure sensitive walkway (PSW), during a STST and WT and in 10 dogs with unilateral cranial cruciate ligament rupture (CCLR) and 18 healthy dogs. Data collected was used to calculate symmetry indices (SI) of ipsilateral and contralateral hindlimbs (HL), diagonal limb pairs (DLP) and ipsilateral limb pairs (ILP).

Results:

The SI of PVF of HL during the WT and STST was 100% and 90% sensitive for discriminating lame and non-lame dogs respectively. The SI of VI of HLs during the WT and STST was 100% and 50% sensitive for discriminating lame and non-lame dogs respectively. Analysis of ipsilateral and diagonal limb pairs did not improve the discrimination in either test. The time taken to collect data from the STST data was shorter than for the WT.

Clinical significance:

Whilst the STST required a shorter time for collection of data than the WT, it did not accurately identify all dogs with lameness associated with CCLD, and thus has relatively limited clinical utility in its tested form.

Introduction:

The visual assessment of lameness in dogs is commonly used to assess the severity of disease and response to treatment, but the correlation of such assessments with objective measures of limb function is poor (Waxman *et al.*, 2008; Oosterlinck *et al.*, 2011). Kinetic gait analysis of dynamic weight-bearing is considered the gold standard objective gait assessment (Ladha *et al.*, 2017), and has been widely used to characterise the effect of medical and surgical interventions of musculoskeletal and neurological conditions in dogs (Borer *et al.*, 2003; Grisneaux *et al.*, 2003; Moreau *et al.*, 2003, 2007; Ballagas *et al.*, 2004; Conzemius *et al.*, 2005; Klaveren *et al.*, 2005; Karnik *et al.*, 2006; Budsberg *et al.*, 2007; Suwankong *et al.*, 2007; Wilson, Roush and Renberg, 2018). However, the acquisition of kinetic data from dogs during dynamic weight bearing is time consuming and thus difficult to incorporate into routine clinical practice, which has precluded its routine use.

Rising from a sitting to standing position is a complex movement requiring the recruitment of multiple muscle groups (Ellis, Rankin and Hutchinson, 2018). Quantifying this movement, for example with kinetic gait analysis, can allow the assessment of physical function in the form of a sit-to-stand test (STST) (Caplan *et al.*, 2014). In humans the STST enables the direct quantification of lower-body functional power which demonstrates significant correlation with measurements of functional ability such as strength, speed, endurance and agility (Gray and Paulson, 2014). The kinematic analysis of stifle movement in healthy dogs during the STST demonstrates excellent

intra- and inter-observer repeatability (Feeney *et al.*, 2007). The range of motion of the hip joint of healthy dogs is increased when compared to dogs with hip dysplasia, and this difference is accentuated with the STST when contrasted with normal walking motion(Souza *et al.*, 2019).

The accuracy of kinetic parameters of the STST to identify lameness caused by CCLR has not been described or compared to other methods of quantitative gait analysis in veterinary medicine to the authors' knowledge. This study aimed to evaluate the asymmetry of weight bearing in dogs with unilateral CCLR using a simple, one stage, STST. We hypothesised that kinetic data acquired from a STST and the conventional walk test (WT) could discriminate dogs with hindlimb lameness associated with cruciate rupture from non-lame dogs, and that the STST would be quicker to complete than the WT.

Materials and methods

Study population

The study was approved by the Veterinary Ethical Review Committee of the Royal (Dick) School of Veterinary Studies (approval number 120.17). Healthy dogs were recruited from staff and students working at the Hospital for Small Animals at the University of Edinburgh, and dogs with cranial cruciate ligament rupture (CCLR) were recruited from owners presenting their pet for treatment of the disease at the same institution. Owners consented for their pet to undergo the testing procedure prior to commencing the study. Eighteen healthy dogs and ten dogs with unilateral lameness attributed to CCLR, were recruited. Healthy dogs were ascribed as such following a complete orthopaedic examination by an ECVS diplomate (xx or xx). The diagnosis of CCLR was based on history, physical exam, radiography and subsequently confirmed by arthrotomy or arthroscopic evaluation of the joint.

79

80 **Protocol**

81 All dogs underwent the same testing procedure which comprised visual lameness assessment and
82 routine orthopaedic examination confirming unilateral lameness (CCLR dogs) or subjective
83 soundness (healthy dogs). All dogs were weighed on an electronic scale before gait analysis to allow
84 normalisation with pressure walkway data. All the patients included in the study were handled by
85 a single operator (AT). All dogs were permitted to walk freely around the gait laboratory for ten
86 minutes and walked over the pressure sensitive walkway (PSW) five times without recording data
87 to permit habituation to the laboratory conditions and the PSW, before being walked over the
88 PSW on a loose lead, a minimum of five times for acquisition of data.

89

90 A 1 m × 0.5 m PSW containing 1.4 sensels per cm^2 was set up as previously described (Fanchon
91 and Grandjean, 2007) and the data analysed using proprietary software (Walkway v7.02; Tekscan).
92 The walkway was calibrated as the per manufacturer's guidelines, and a proprietary equilibration
93 file (20 PSI) was used when gathering data. The data was collected at a 60Hz sampling rate. The
94 PSW was placed in the middle of a 13.6m x 5.3m room and covered with a 5m x 50cm x 2mm
95 rubber matt as previously described (Waxman *et al.*, 2008; Bockstahler *et al.*, 2009).

96

97 A Microsoft 1080 HD camera (Microsoft LifeCam Studio Webcam, Microsoft) was used to
98 capture video recordings of the dogs on the PSW. The camera was synchronised with the PSW
99 and the video recording was used to ensure the correct foot print recognition by the walkway
100 software. The dog's velocity and acceleration during kinetic gait data collection was estimated from
101 the video footage using five markers placed 1 metre apart. The mean gait velocity of each dog was
102 recorded as the mean velocity of the 4 velocity measurements, recorded between each marker on
103 each trial. The two gait tests were always performed in the same order: WT then STST. The time

104 measured to undertake each test was measured with a stopwatch. Data were exported from the
105 proprietary gait software for each of the two tests (WT, STST) for statistical analysis.
106
107 The "walk" test (WT)
108 Dogs were walked on a leash, by the same handler, in a straight line across the PSW until five valid
109 trials were achieved. Each dog was allowed to walk at its preferred velocity. A trial was considered
110 valid when the dog walked across the full length of the PSW, in a straight line, at a gait velocity of
111 +/- 0.5m/s range, with all four paws fully contacting the plate surface as previously described
112 (Bockstahler *et al.*, 2009; Oosterlinck *et al.*, 2011). Trials were excluded if the dog ran, trotted,
113 paused, stopped or turned its head on the walkway. This was repeated until five valid trials were
114 obtained. Peak vertical force (PVF), vertical impulse (VI), velocity and stance time (StT) were
115 calculated. PVF and VI were expressed as a percent of body weight. The PVF and VI were
116 recorded for all four limbs, and the average of the five trials was calculated for analysis.
117
118 Sit to stand test (STST)
119 Dogs were sat on the PSW and then encouraged to stand up and walk away from the PSW. Each
120 dog was allowed to stand up and walk away at its preferred velocity. A trial was considered valid
121 when the dog stood up on the PSW, with all four paws fully contacting the plate surface at least
122 once. This was repeated until three valid trials were obtained. PVF and VI were expressed as a
123 percent of body weight. The PVF and VI were recorded for all four limbs, and the average of the
124 three trials calculated for statistical analysis.
125 The time taken to perform each test was recorded for each dog.
126
127 **Statistical analysis**
128 Each dataset was assessed for the normality of distribution by visual analysis of individual value
129 plots. The mean ± 95% confidence intervals (95% CI) and range were determined for forelimbs

and hindlimbs of each dog: gait velocity, StT, PVF, and VI. Three measures of symmetry were calculated for each dog. The symmetry index (SI) for each variable was calculated as previously described (Fanchon and Grandjean, 2007; Bockstahler *et al.*, 2009) as follows: SI between the hindlimb pairs (HL) was calculated (=100x([AHL-CHL]/[AHL+CHL]), where AHL is the affected hindlimb and CHL is the contralateral hindlimb). The SI between the diagonal limb pair (DLP) was calculated (=100x([AHL-CFL)]/[AHL+CFL]), where CFL is the contralateral forelimb). The SI between ipsilateral limb pairs (ILP) was calculated (=100x([AHL-IFL]/[AHL+IFL])).

The age, weight and time taken to complete each test, for each group were assessed for normality by graphical representation, and compared by use of independent two-sample t-tests. The kinetic and time variables for each group were assessed for normality by graphical representation, and compared by use of an independent two-sample t-test, with Bonferroni correction, to identify differences between the healthy and CCLR groups. Thus, a total of 24 test conditions were assessed (comparison of SI of PVF and VI for HL, DLP and ILP during WT and STST and comparison of SI of StT for HL, DLP and ILP during WT and STST). As an optimal diagnostic test should be able to completely discriminate between healthy and CCLR subjects, the upper range of the SI measured in the healthy group was selected as the cut-off value to measure the sensitivity and negative predictive value of each measure (as the specificity and positive predictive value will both be 100%).

Results:

The healthy group comprised of eighteen dogs, thirteen males and five females, all neutered, aged from 1 year to 12 years (mean 5.1 years +/- 1.7years) and weighing between 12kg and 43kg (24kg +/- 4.1kg). This group consisted of five crossbred dogs, two Springer Spaniels, three Border Collies, two Staffordshire Bull Terriers, one Lurcher, one Greyhound, one Labrador Retriever,

one Cocker Spaniel, one Dalmatian and one Husky. The CCLR group comprised ten dogs, six males and four females, all neutered, aged from 4 years to 10 years (7.1 years +/- 1.3years) and weighing between 17kg and 72 kg (35kg+/-10.0kg) and consisted of two Labrador Retrievers, two Staffordshire Bull Terriers, one Border Collie, one crossbred dog, one Lurcher, one Rottweiler, one Bullmastiff and one Springer Spaniel. The CCLR group was significantly heavier ($p=0.03$) than the healthy group, but not significantly older ($p=0.13$). All dogs permitted the three trials of the STST, and five valid WT trials. The mean time taken to collect the WT dataset was 664 seconds (s) (range 449s to 1320s). This was significantly longer ($p=0.019$) than the mean time to taken to collect the STST data (435 s, range 208s to 960s), however the average time to take each individual repeat was slightly longer (145s per valid repeat) compared to the WT (132s per valid repeat).

Asymmetry in StT between the healthy and CCLR groups did not differ significantly in either test.

The mean SIs of the ground reaction forces (GRFs), HL, ipsilateral limb pair (ILP) and diagonal limb pair (DLP), measured in the healthy and CCLR groups, are presented in Figure 1, and sensitivity of those measures is presented in Supplementary Table 2. The SI of the HL GRFs during the WT were significantly different between the healthy and CCLR groups (Figure 1, Supplementary Table 1). The SI of the HL GRFs during the WT were 100% sensitive for classifying the healthy and CCLR dogs (Supplementary Table 2). The SIs of the DLP GRFs during the WT were 100% sensitive (PVF) and 90% sensitive (VI) for classifying the healthy and CCLR dogs. The SI of the ILP GRFs during the WT were 100% sensitive (PVF) and 80% sensitive (VI) for classifying the healthy and CCLR dogs.

The SI of the HL GRFs measured during the STST were 90% sensitive (PVF) and 50% sensitive (VI) for classifying the healthy and CCLR dogs. The SIs of the DLP GRFs during the STST were poorly sensitive (PVF 40%, VI 50%) for classifying the healthy and CCLR dogs. The SIs of the

ILP GRFs during the STST were 0% sensitive (PVF) and 33% sensitive (VI) for classifying the healthy and CCLR dogs.

Discussion:

In the present study, the clinical utility of a simple, STST was investigated, and compared to the WT (Lascelles *et al.*, 2006; Light *et al.*, 2010; Clough *et al.*, 2018; Wilson, Roush and Renberg, 2018) which is another method of quantitative gait analysis. Objective measures of lameness (SI of the GRF expressed during each test) were recorded and compared by different analysis techniques. The STST test was achievable in all patients. However, the time advantage was less than expected, and the STST did not effectively discriminate between dogs with hindlimb lameness associated with CCLR and non-lame dogs.

The SIs of PVF and VI are common kinetic gait parameters used in the diagnosis of unilateral lameness in dogs (Fanchon and Grandjean, 2007) and have been found to effectively discriminate between lame and non-lame hindlimbs (Budsberg *et al.*, 1993). Although the STST accentuated the difference in SIs between the CCLR and healthy groups, the difference was also more variable across the three repeats assessed which reflected the observation that the dogs didn't rise in the same manner on every test. This variability impacted on the ability of the test to discriminate between non-lame and dogs with lameness associated with CCLR.

Compensatory weight-shifting mechanisms in dogs with unilateral lameness is well recognised. In dogs with hindlimb lameness, compensatory load has been shown to shift to the ipsilateral forelimb when analysing PVF and VI at walk (Katic *et al.*, 2009; Fischer *et al.*, 2013) and trot (Fischer *et al.*, 2013). This is at odds with our observation that the SI of PVF and VI of DLPs was more sensitive than ILPs, but ILP and DLP were both still considerably less discriminatory for identifying lame dogs than HLs alone in the WT. The reasons for this difference with previous

208 reports is unclear, but the nature of the hind limb lameness, our use of a pressure platform rather
209 than an instrumented treadmill, and the heterogeny of the breeds in our study may have
210 contributed. The SI of PVF and VI with DLP and ILP in the STST did not improve the ability to
211 discriminate lameness associated with CCLR when compared to the HL alone suggesting that
212 compensatory load shifting was not occurring consistently in the STST either.
213
214 Asymmetry in StT between the lame and non-lame groups (healthy and CCLR groups) was not
215 discriminatory for the identification of lameness in this cohort. An increase in CHL StT might be
216 expected as a compensatory load shifting mechanism to reduce load-bearing of the AHL as has
217 been shown with cinematography and electrogoniometry in horses (Ratzlaff, Grant and Adrian,
218 1982; Clayton, 1986). In dogs however, morphometric differences such as overall body size and
219 limb length rather than body mass, are responsible for as much as 20% of StT variance (Budsberg,
220 Verstraete and Soutas-Little, 1987; Fischer *et al.*, 2013). These variables were not controlled for in
221 this study, and may partially explain why these differences in this measure were not observed
222 (Abdelhadi *et al.*, 2013; Bosscher *et al.*, 2017).
223
224 The STST and the WT employ different movements and therefore some dogs with orthopaedic
225 disease may objectively demonstrate lameness with one method but not another. The clinical
226 application of kinetic gait analysis is challenging because it requires multiple passages across the
227 platform to obtain enough data to reproducibly identify unilateral lameness; large variances in the
228 data occur as a result of different stance times, velocity and/or acceleration (Hans *et al.*, 2014;
229 Volstad, Nemke and Muir, 2016). Additionally, thus far the time burden to obtain sufficient
230 numbers of "repeats" to obtain valid and useful data, and the space required to create a runway
231 has precluded its use in the clinical setting. For this reason, 5 repeats of the WT test were
232 undertaken and 3 repeats of the STST.
233

This study has several limitations. Firstly, as a pilot study of the STST there was no prior knowledge of variance of this data upon which to select a sample size. However, the fundamental premise was that a useful test should be able to discriminate all dogs with unilateral lameness caused by CCLR from non-lame dogs, and thus 5 valid WT trials and 3 STST trials per dog were obtained in this study. Five valid WT trials is the generally accepted number to produce valid data (Torres, 2020) though the time required to collect 5 valid WT trials is considerable with a pressure platform 1m in length. Increasing the number of STST trials may have reduced the variance of the SI data produced but the number of trials selected was limited to those considered acceptable by our ethical review board, and time-appropriate for the clinical setting. Rising from a prone position is considered a more painful movement than walking, and thus the number of repeats was limited for ethical reasons, as the expectation was that the lameness would be accentuated by this movement, but this will have contributed to the increased variability. The severity of lameness was not standardised for the purpose of the study, although all dogs were able to weight bear on their affected limb. No imaging of the healthy group prior to enrolment into the study was performed. SI in healthy dogs should also be interpreted with caution. It is a one point in time test and may not reflect the gait at home. Additionally, dogs can demonstrate significant asymmetry between healthy limbs (Torres, 2020). This natural variation can therefore result in both false positives and negatives.

In conclusion, a three repeated STST has a limited clinical utility for the identification of lameness associated with CCLR in dogs, and the SI of kinetic data of the hind limbs alone using the WT remains the most sensitive tool for identification.

Keywords: sit to stand test, kinetic gait analysis, canine, pressure sensitive walkway, hindlimb lameness

Abbreviations:

STST sit to stand test

WT walk test

CCLR cranial cruciate ligament rupture

SD standard deviation

PSW pressure sensitive walkway

StT stance time

PVF peak vertical force

VI vertical impulse

SI symmetry index

AHL affected hindlimb

CHL contralateral hindlimb

DLP diagonal limb pair

IFL ipsilateral forelimb

CFL contralateral forelimb

GRF ground reaction force

ILP ipsilateral limb pair

CV coefficient of variation

WDP weight distribution platform

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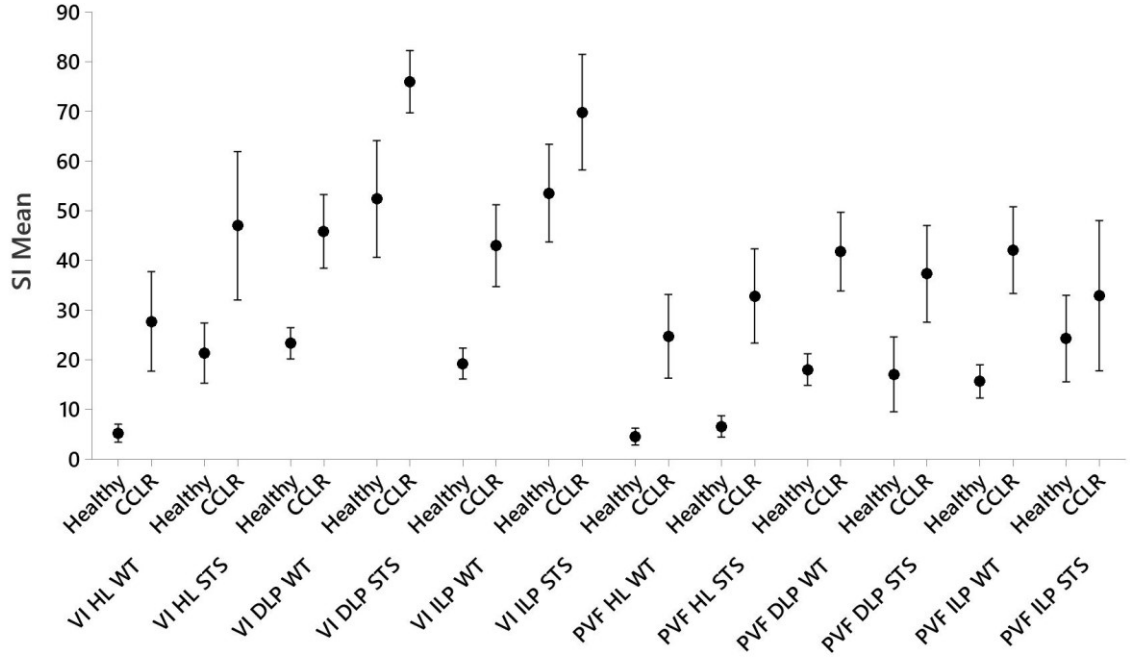
Conflict of interest: none declared

Figure legends:

Figure 1 – Mean ± 95% CI values of symmetry index (SI) comparing healthy and CCLR groups for both tests: walk test (WT) and sit to stand test (STST), corrected to mean bodyweight. Hindlimb vertical impulse (VI HL), hindlimb peak vertical force (PVF HL), diagonal limb pair vertical impulse (VI DLP), diagonal limb pair peak vertical force (PVF DLP), ipsilateral limb pair vertical impulse (VI ILP), ipsilateral limb pair peak vertical force (PVF ILP). n= 18 dogs in

healthy group, 10 dogs in CCLR group; error bars represent 95% CI;



	Mean CCLR	Min CCLR	Max CCLR	95% CI CCLR	Mean healthy	Min healthy	Max healthy	95% CI healthy	Mean Difference (% SI)	Bonferroni correct P value
SI VI HL WT	28	14	59	9	5	0	13	2	19	<0.001
SI PVF HL WT	25	15	54	7	5	0	12	2	18	<0.001
SI VI DLP WT	46	32	68	6	23	10	35	3	40	<0.001
SI PVF DLP WT	42	29	69	7	18	4	27	3	35	<0.001
SI VI ILP WT	43	27	66	7	19	9	29	3	36	<0.001
SI PVF ILP WT	42	27	70	8	16	3	27	3	34	<0.001
SI VI HL STST	47	14	78	13	21	0	43	6	34	<0.001
SI PVF HL STST	33	13	61	8	7	0	16	2	25	<0.001
SI VI DLP STST	76	60	86	5	52	10	75	11	71	0.10
SI PVF DLP STST	37	20	62	8	17	1	42	7	29	0.04
SI VI ILP STST	63	50	93	10	48	16	78	9	53	0.93
SI PVF ILP STST	30	6	56	13	22	3	60	8	17	1.00

Supplementary Table 1 – Mean, minimum and maximum values of symmetry index (SI) (± SD), coefficients of variation (CV) and statistical analysis of kinetic data (vertical impulse (VI), peak vertical force (PVF)) for healthy and cranial cruciate ligament rupture (CCLR) groups for hindlimbs (HLs), diagonal limb pairs (DLPs), ipsilateral limb pairs (ILPs) in for both tests: walk test (WT) and sit to stand test (STST), corrected to mean bodyweight.

Table abbreviations:

STST sit to stand test

WT walk test

CCLR cranial cruciate ligament rupture

SD standard deviation

PSW pressure sensitive walkway

StT stance time

PVF peak vertical force

VI vertical impulse

SI symmetry index

AHL affected hindlimb

CHL contralateral hindlimb

DLP diagonal limb pair

IFL ipsilateral forelimb

CFL contralateral forelimb

GRF ground reaction force

ILP ipsilateral limb pair

	Sensitivity	Specificity
SI VI HL WT	100	100
SI PVF HL WT	100	100
SI VI DLP WT	90	100
SI PVF DLP WT	100	100
SI VI ILP WT	80	100
SI PVF ILP WT	100	100
SI VI HL STST	50	100
SI PVF HL STST	90	100
SI VI DLP STST	50	100
SI PVF DLP STST	40	100
SI VI ILP STST	33	100
SI PVF ILP STST	0	100

Supplementary Table 2 – Sensitivity and specificity values for symmetry index (SI) of kinetic data (vertical impulse (VI), peak vertical force (PVF)) to discriminate healthy and cranial cruciate ligament rupture groups. Hindlimbs (HLs), diagonal limb pairs (DLPs), ipsilateral limb pairs (ILPs) for both tests: walk test (WT) and sit to stand test (STST), corrected to mean bodyweight.

Table abbreviations:

STST sit to stand test

WT walk test

CCLR cranial cruciate ligament rupture

SD standard deviation

PSW pressure sensitive walkway

StT stance time

PVF peak vertical force

VI vertical impulse

SI symmetry index

AHL affected hindlimb

CHL contralateral hindlimb

DLP diagonal limb pair

IFL ipsilateral forelimb

CFL contralateral forelimb

GRF ground reaction force

ILP ipsilateral limb pair