

# Water depth and speed may have an opposite effect on the trunk vertical displacement in horses trotting on a water treadmill

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## OBJECTIVE

To measure the trunk vertical displacement (VD) in horses trotting on a water treadmill (WT) at different water depths (WDs) and speeds.

## ANIMALS

6 sound Standardbred horses (median age 12 years [IQR:10.5-12]).

## METHODS

The horses were trotted on a WT at 2 speeds (3.5 m/s and 5 m/s) and during 4 conditions: dry treadmill (DT), WD at mid-cannon (WD-CAN), mid-radius (WD-RAD), and shoulder (WD-SHOUL). The dorsoventral movement was obtained with accelerometers placed over the withers, thoracolumbar junction (T18), tuber sacrale (TS), and sacrum (S5). The VD was defined with the median value of the upward (Up) and downward (Down) amplitudes of the vertical excursion during each stride. The difference of VD at each sensor location was compared between the DT and the 3 WDs, and between the 2 trotting speeds for the same condition.

## RESULTS

The VD amplitudes were significantly increased at any sensor location when trotting in water at WD-CAN and WD-RAD compared to DT ( $P < .05$  for all), with the highest increase at WD-RAD and T18. When the speed increased from 3.5 to 5 m/s, the VD amplitudes were significantly decreased at T18 at each water level ( $P = .03$ ), and at WD-RAD only for the withers and TS ( $P = .03$ ).

## CLINICAL RELEVANCE

Both water depth and speed affect the trunk VD in horses at trot on a WT with an opposite effect. The VD increases when increasing the WD up to mid-radius, while the VD decreases when increasing the trotting speed, with the main effects observed at the thoracolumbar junction.

**Keywords:** Equine, water treadmill, trot, trunk, accelerometry

**W**ater treadmill (WT) exercise has become a popular training and rehabilitation modality for equine athletes over the past decade. Parallel with the spread of the WT in research, therapy centers, or private yards, practical guidelines for indications and contraindications for the use of this modality have increased considerably.<sup>1-4</sup>

The decision to include the WT in a training or rehabilitation program for horses is usually made

to take advantage of the intrinsic properties of the water. Buoyancy decreases the body weight<sup>5</sup> and the vertical ground reaction forces<sup>6</sup> during immersion, while the drag force counteracts the forward movement of the horse, increasing the energy expenditure as an aerobic type of exercise.<sup>7,8</sup> Further, the hydrostatic pressure may improve the proprioceptive neuromuscular function and postural stability.<sup>9</sup>

Several studies have demonstrated that kinematics of limbs,<sup>10-14</sup> back, and pelvis<sup>14-16</sup> of horses are significantly modified increasing the water depth. Nonetheless, the protocols described in the literature or used in practice are variable in terms of

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a combination of water depth, gait, and speed, thus the appropriate selection of these parameters is a current concern in the equine field.

Most of the research on equine WT has described movement adaptations in water at slow walk and speed ranging from 0.8 to 1.6 m/s.<sup>6,10-16</sup> However, an international survey conducted in the United Kingdom reported that the average walking speed used in practice is usually higher (1.75 m/s; range = 0.7 to 2.8).<sup>17</sup> The walk is the gait most commonly used especially for rehabilitation purposes, but some training centers also perform WT sessions at the trot with an average speed of 4.3 m/s (range = 3.4 to 5).<sup>17</sup> To date there are few published reports describing the use of the trot in WT protocols for horses,<sup>4,17-19</sup> and its use in practice is mainly empirical rather than based on scientific data.

Two preliminary studies investigating the kinematics of the equine trunk at the trot on the WT suggested that the vertical displacement of the withers<sup>18</sup> and pelvis<sup>18,19</sup> would increase when trotting in water up to the carpus or mid-radius levels compared to the dry belt. However, there is still a paucity of data concerning the analysis of the whole trunk movement at the trot during this type of exercise, especially at the thoracolumbar junction.

This study aimed: (1) to measure the vertical displacement (VD) of the trunk in horses trotting on a WT at different water depths (WDs) and compare it to the dry condition; (2) to assess whether the trotting speeds will influence the VD.

It was hypothesized that (1) the trunk VD would increase passing from the dry condition to water up to an intermediate level; (2) for a same WD, the VD would decrease by increasing the trotting speed.

## Material and Methods

### Horses

Six sound French Standardbred horses (3 females, 3 geldings, median age 12 years [interquartile ranges = 10.5 to 12]; median weight 556 kg [538 to 583]) from the "Centre d'Imagerie et de Recherche sur les Affections Locomotrices Equines" (CIRALE) were used for the study. The horses were similar in size (mid-cannon height: 30 cm [28.5 to 30]; mid-radius height: 67.5 cm [61.7 to 68]; point of the shoulder: 109 cm [107.5 to 111.5]; withers height: 158.2 [157.2 to 159]). The horses were attested to sound during spontaneous locomotion at the walk and the trot in a straight line and firm surface through a subjective lameness examination performed by 2 of the authors (CF and SJ). An additional quantitative lameness assessment was carried out in the same circumstances with an inertial motion sensor unit (IMU) system (EQUYSIM by Arioneo) to assess their symmetry at the trot.

The WT model (Aquatrain Horse-Gym-2000, model W3) used in the study had a running surface measuring 3.3 m long, 1.06 m in width between the walls and glass walls at each side (**Supplementary Figure S1**). The walls measured 150 cm high. This WT could reach a maximum water height of 120 cm and

a maximum speed of 8.5 m/s (ie, 31 km/h), allowing to analyze the horse's gait at trotting speeds.

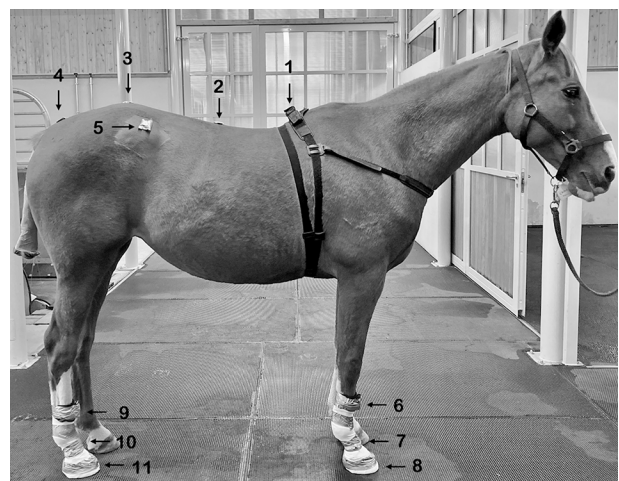
The horses were previously acclimatized to the WT with a minimum of 2 sessions of 15 minutes at the walk and trot and considered acclimatized when capable to maintain a regular gait in all tested conditions of water height and speed. All the horses had previous similar experiences with water exercise (WT or swimming) in the facility. Overall, 2 sessions of approximately 20 to 25 minutes were performed for each horse on different days during the habituation period. The present work is part of a larger project that was approved by the Ethics Committee ComEthAnses/ENVA/UPEC (protocol code 13/12/18-8 and date of approval: December 13, 2018).

### Experimental design and data collection

For the overall protocol of the study, the horses were equipped with 11 wireless synchronized IMUs (Blue Trident, dual-g sensors, Vicon Motion Systems Ltd) with a full-scale range of 16g (Low-g), 2000°/s, 16 bits, and sampling at a frequency of 225Hz.

Five IMUs were placed on defined locations on the dorsal midline and pelvis of each horse: on the withers, the thoracolumbar junction (T18), the tuber sacrale (TS), the sacrum (S5), and the right tuber coxae (TC). These areas were identified by digital palpation except for the spinous process of T18 which was radiographically identified with a spheric marker. Three IMUs were also positioned on the dorsal aspect of the cannon bone, the pastern, and the hoof wall of the right forelimb and the right hindlimb (**Figure 1**).

The devices used were waterproof; thus, they were protected with a simple tape and glued directly to the horse's back, except for the withers sensor that was placed in a girth with a breastplate attachment which was adapted to the individual horse. The limb accelerometers at the level of the cannon bone were integrated into a boot, while those of the



**Figure 1**—Inertial motor sensor units (IMUs) placement for data collection. 1: Withers, 2: Thoracolumbar junction (T18), 3: Tuber sacrale, 4: Sacrum (S5), 5: Right tuber coxae; Right forelimb: 6: Cannon bone, 7: Pastern, 8: Hoof wall; Right hindlimb: 9: Cannon bone, 10: Pastern, 11: Hoof wall.

pastern and foot were secured with a double-sided tape and a very light bandage, to minimize their displacement. Placement and fixation of the IMUs was performed by the same operator (CF) to ensure standardization of the procedure.

The positioning of the IMUs on the dorsal midline was defined with the positive craniocaudal ( $x$ ) axis pointing toward the front of the WT, the positive mediolateral ( $y$ ) axis pointing toward the right side of the treadmill, and the positive dorsoventral ( $z$ ) axis pointing upwards.

## WT sessions and protocol

Each horse underwent 3 WT sessions of approximately 25 minutes, which were randomized and spaced at least 24 hours apart. Each session corresponded to 1 of the 3 water heights studied: water at the mid-cannon bone (WD-CAN), mid-radius (WD-RAD), and at the point of the shoulder (WD-SHOUL). The dry treadmill (DT) was considered as the control condition for each of them.

Each WT session started with 2 minutes of warming up at the walk on the treadmill without water. Then, 2 data collections were made while the horses trotted: (1) at the DT; (2) at the selected WD. During both conditions, 2 trotting speeds were randomly tested (3.5 m/s and 5 m/s). Data were collected during successive 20 seconds for each trotting speed. Between the 2 measurements, the horses walked at the same controlled speed (1.4 m/s) while the WT was filled. To ensure repeatability of the measurements, all data collections at the selected WD were made at the same time (20 minutes after the beginning of the protocol), which corresponded approximately to the time needed for the aquatrainer to reach the highest water level tested (WD-SHOUL). The protocol was summarized using a visual flow-chart (**Supplementary Figure S2**).

Video recordings were acquired with 3 cameras placed on the right side of the WT, behind the horse, and behind on the top to observe the horse's gait and posture during the session. The horses were not held, but a person stayed on the left side near the head during the entire session for safety reasons.

## Data processing and analysis

Before starting the session, calibration of the IMUs was made with the horse standing in the holding room. Data from limb kinematics and those obtained from the tuber coxae movements were simultaneously collected but analyzed in a separate study. In this part of the research project, only data from the sensors placed on the dorsal midline were analyzed to assess the trunk VD. Data were processed with MATLAB Software (Matlab R2021a, The MathWorks Inc). At each sensor location, the acceleration signal along the dorsoventral ( $z$ ) axis was measured and then double integrated into displacement, following published methods.<sup>20</sup>

As the trunk of the horse moves twice up and down with a double sinusoid corresponding to the left and right stance phases during a normal trot stride, 4 values were obtained to describe the VD at

each sensor location: the absolute value of the lowest (Min) and highest (Max) altitudes of the vertical excursion; the absolute value of the upward (Up) and downward (Down) amplitudes for the left and right stance phases (**Supplementary Figure S3**). The values of the Up and Down amplitudes were considered to represent the trunk VD. The stride frequency (SF) at the 2 trotting speed was also measured and compared between the DT and all water conditions.

The statistical analysis was conducted with XLSTAT Biomed (Version 2.2, Addinsoft). Data were tested for normality of distribution using Shapiro-Wilk tests. In total, 73 of the 576 datasets tested were found to be not normally distributed. Nonparametric tests were used, and data of the vertical displacement were presented as medians and their interquartile range in square brackets (median [25th and 75th percentiles]).

Wilcoxon Signed Rank test was used to compare the median difference in the trunk VD of each anatomical location between the control condition (DT) and each WD during the same session and to compare the VD values between the 2 different trotting speeds (3.5 and 5 m/s). The Friedman's test for multiple comparison was used to check for differences between the 3 WDs at each anatomical location and fixed speed, followed by a post hoc analysis using the Nemenyi's procedure. Those tests were also used to compare the SF between the DT and each WD, and between the 3 WDs. The statistical significance was set at  $P < .05$  for all the tests.

## Results

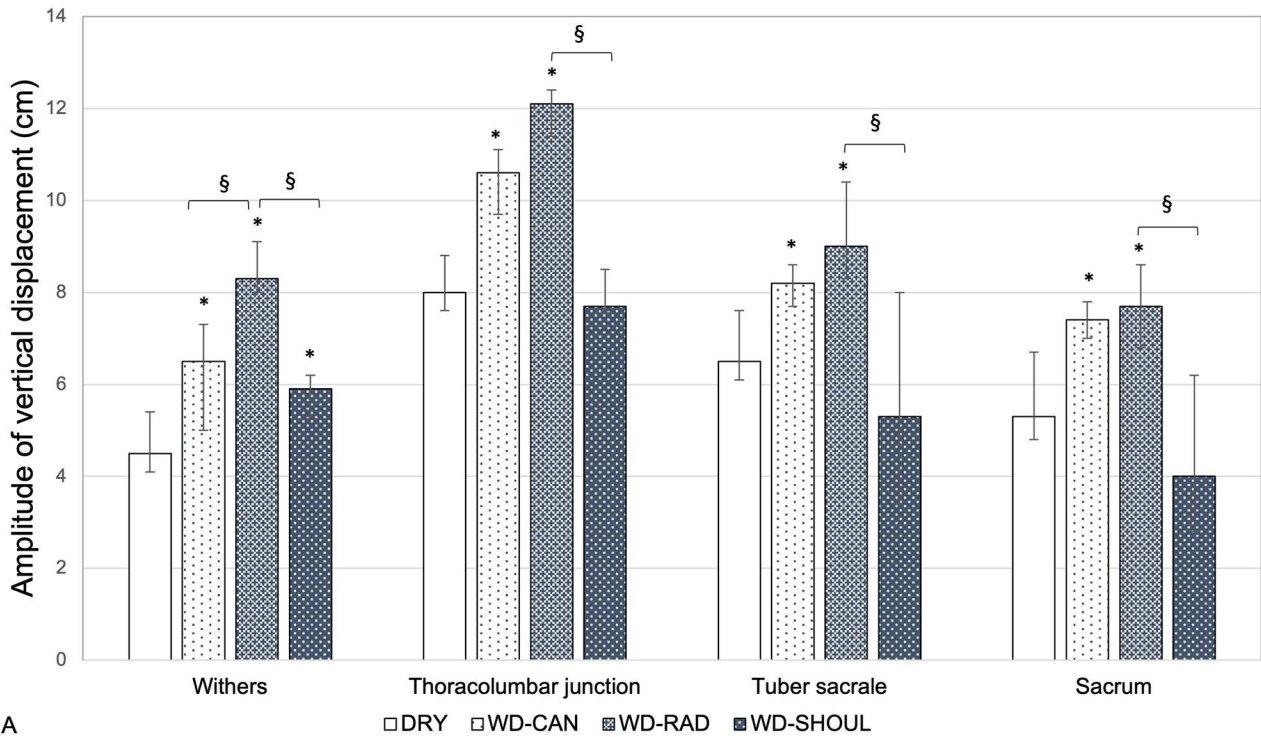
All the horses concluded the protocol and were able to maintain a regular and symmetrical gait during all conditions. For a given trotting speed, the SF was significantly different in water compared to DT and decreased while increasing the WD until the shoulder level ( $P < .05$  for all). At 3.5 m/s, the median SF fell from 1.28 strides/s at the DT condition to 1.12 strides/s at WD-SHOUL ( $P = .03$ ), while at 5 m/s it fell from 1.47 strides/s to 1.25 strides/s at the WD-SHOUL ( $P = .02$ ). At the highest trotting speed, the SF at WD-RAD and WD-SHOUL was significantly decreased also compared to WD-CAN ( $P = .02$ ) (**Supplementary Figure S4**).

## Trunk VD at different water depths

The WD significantly influenced the trunk VD while trotting at fixed speed. The median VD amplitudes at any sensor location were significantly different when trotting in water, with higher values at WD-CAN and WD-RAD compared to DT at both trotting speeds ( $P < .05$  for all) (**Figure 2; Table 1 and 2**).

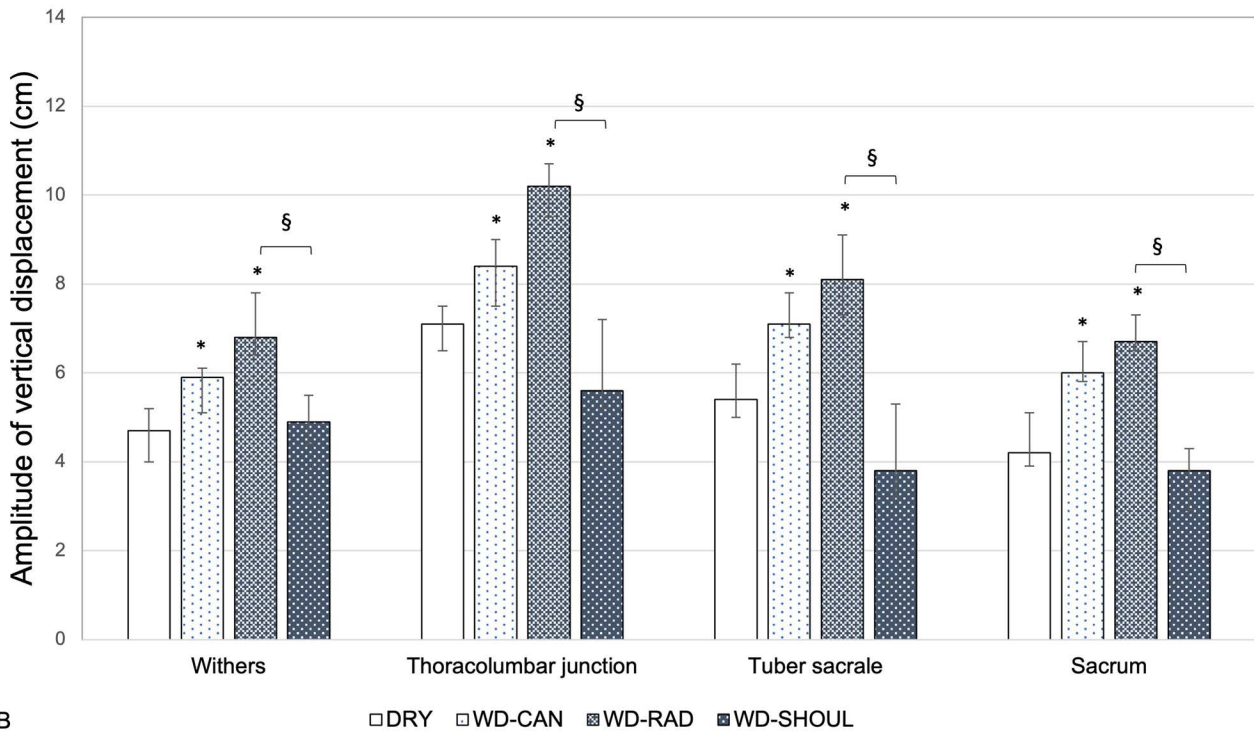
The highest values of VD were detected when trotting at 3.5 m/s at WD-RAD and at the level of T18 (Up: 12.1 cm [11.4 to 12.4]; Down: 12 cm [11.3 to 12.3]; **Figure 2**), with a significant increase of 4.1 cm [3.1 to 4.6] and 3.9 cm [2.1 to 4] of the Up and Down values, respectively, compared to DT ( $P = .03$ ) (**Table 1**), but not significantly different from WD-CAN ( $P = .05$ ).

### Trot 3.5 m/s



A

### Trot 5 m/s



B

**Figure 2**—Amplitude of the trunk vertical displacement (cm) of 6 horses trotting on a water treadmill at different water depths (WDs): DRY = control condition; WD-CAN = mid-cannon bone; WD-RAD = mid-radius; WD-SHOUL = shoulder point. (a) trotting speed: 3.5 m/s; (b) trotting speed: 5 m/s. The columns represent the median values of the upward amplitude of the vertical displacement and the lines extending vertically from the column indicate the interquartile range. \*Significantly different from control (DRY) condition ( $P < .05$ ). §Significantly different from WD-RAD ( $P < .05$ )

**Table 1**—Median differences of the vertical displacement of the trunk in 6 horses when trotting on a water treadmill at fixed speed (3.5 m/s) and different water depths (WD-CAN = mid-cannon bone; WD-RAD = mid-radius; WD-SHOUL = shoulder point) compared to the dry condition.

	WD-CAN		WD-RAD		WD-SHOUL	
	Median (cm)	IQR	Median (cm)	IQR	Median (cm)	IQR
Withers						
Up	2.0	[1.1, 2.9]*	3.8	[3.4, 4.2]*	1.4	[1.0, 1.7]*
Down	1.9	[3.0, 4.2]*	3.8	[3.0, 4.2]*	1.3	[1.0, 2.6]*
T18						
Up	2.6	[1.4, 2.9]*	4.1	[3.1, 4.6]*	-0.3	[-1.0, -1.7]
Down	2.7	[1.4, 3]*	3.9	[2.1, 3.3]*	-0.2	[-1.4, -1.7]
Tuber sacrale						
Up	1.7	[1.1, 2.3]*	2.5	[2.3, 3.0]*	-1.3	[-2.3, 0.4]
Down	1.7	[0.8, 2.3]*	2.6	[2.3, 3.0]*	-1.3	[-2.3, 0.5]
S5						
Up	2.0	[1.3, 2.4]*	2.2	[2.1, 2.3]*	-1.3	[-1.7, 0.6]
Down	2.0	[1.2, 2.4]*	2.2	[2.1, 2.4]*	-1.3	[-1.7, 0.6]

Up: the absolute value of the upward amplitude during the propulsion phase; Down: the absolute value of the downward amplitude during the absorption phase.

Data are presented as medians and their interquartile ranges in a square brackets.

\*Significantly different to control (DRY) condition ( $P < .05$ ).

**Table 2**—Median differences of the vertical displacement of the trunk in 6 horses when trotting on a water treadmill at fixed speed (5 m/s) and different water depths (WD-CAN = mid-cannon bone; WD-RAD = mid-radius; WD-SHOUL = shoulder point) compared to the dry condition.

	WD-CAN		WD-RAD		WD-SHOUL	
	Median (cm)	IQR	Median (cm)	IQR	Median (cm)	IQR
Withers						
Up	1.2	[0.7, 1.9]*	2.1	[2.0, 2.8]*	-0.2	[-1.0, 1.7]
Down	1.2	[0.8, 1.3]*	2.1	[2.0, 2.7]*	0.1	[-1.0, 1.7]
T18						
Up	1.3	[1.4, 2.9]*	3.0	[2.1, 3.5]*	-1.3	[-1.5, -0.3]
Down	1.5	[1.4, 3.0]*	2.8	[2.0, 3.5]*	-1.4	[-1.4, -1.7]
Tuber sacrale						
Up	1.7	[1.3, 2.0]*	2.4	[2.3, 3.0]*	-1.1	[-1.9, 1.1]
Down	1.7	[1.3, 1.8]*	2.5	[2.3, 2.8]*	-1.1	[-2.3, 1.6]
S5						
Up	1.8	[1.3, 2.2]*	2.5	[1.6, 2.7]*	-0.4	[-1.5, 0.3]
Down	1.9	[1.5, 2.3]*	2.6	[2.4, 2.7]*	-0.4	[-1.4, 0.4]

Up: the absolute value of the upward amplitude during the propulsion phase; Down: the absolute value of the downward amplitude during the absorption phase.

Data are presented as medians and their interquartile ranges in a square brackets.

\*Significantly different to control (DRY) condition ( $P < .05$ ).

Similarly, the VD amplitude at the withers reached the highest values at WD-RAD and slow trot (Up: 8.3 cm [8 to 9.1]; Down: 8.2 cm [7.8 to 5]) with a significant increase of 3.8 cm [3.4 to 4.2] of the Up and Down values compared to DT ( $P = .03$ ) (Table 1). The VD of the withers at WD-RAD differed significantly also from WD-CAN ( $P = .03$ ) and WD-SHOUL ( $P = .03$ ) (Figure 2).

The highest value of VD amplitude at the TS was also observed when trotting at 3.5 m/s at WD-RAD (Up: 9 cm [8.3 to 10.4]; Down: 9.3 cm [8.3 to 10.4]), but a smaller increase compared to DT was detected (2.5 cm [2.3 to 3] and 2.6 [2.3 to 3] of the Up and Down values, respectively, compared to DT;  $P = .03$ ). At the level of the sacrum, the amount of VD amplitude was similar to WD-CAN and WD-RAD at both speeds, without statistically significant differences between these conditions ( $P > .05$ ) (Figure 2).

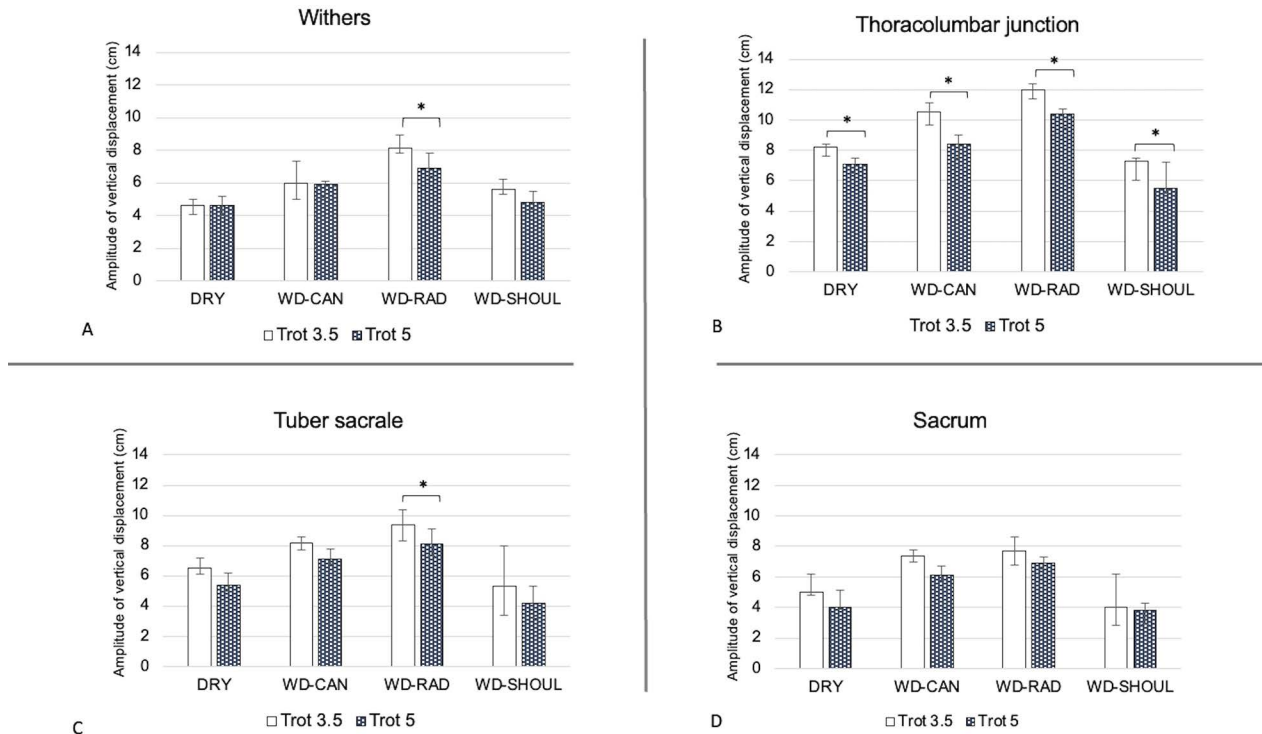
When the water was at the highest level (WD-SHOUL), the VD amplitude was significantly increased compared to DT only at the level of the withers and during slow trot, with an increase of 1.4 cm [1 to 1.7] and 1.3 cm [1 to 1.6] of the Up and Down values, respectively, compared to DT ( $P = .03$ ) (Table 1). For every anatomical location, there was a statistically significant decrease in the VD values at WD-SHOUL compared to WD-RAD ( $P < .05$  for all) (Figure 2). Except for the withers, lower values of VD amplitude were detected at each anatomical location when trotting at the highest water level compared to DT or low (WD-CAN) water level, but they were not statistically different ( $P > .05$  for all) (Figure 2).

### Trunk VD at different trotting speeds

The trotting speed significantly influenced the trunk VD of the thoracolumbar junction at each

condition (**Figure 3**). Increasing the trotting speed, the VD amplitude significantly decreased at T18 when trotting on the dry belt, but this was more pronounced in presence of water, especially at WD-CAN with a significant decrease of  $-2.1$  cm [2.4; 1.7] and  $-1.9$  cm [2.2; 1.4] of the Up and Down values, respectively, when trotting at 5 m/s compared to

3.5 m/s ( $P = .02$ ; **Table 3**). A similar decrease was observed at WD-RAD when trotting at 5 m/s (Up:  $-1.6$  cm [-2.4; -1.3]; Down:  $-1.8$  cm [-2.7; -1.6];  $P = .03$ ) and WD-SHOUL (Up:  $-1.8$  cm [-2.1; -1.3]; Down:  $-1.8$  [-2.1; -1.3];  $P = .03$ ). At the withers and TS, the VD amplitude was significantly decreased when trotting at 5 m/s compared to 3.5 m/s only at



**Figure 3**—Amplitude of the trunk vertical displacement (cm) of 6 horses trotting on a water treadmill at 2 speeds (3.5 m/s and 5 m/s). The values at each anatomical location were compared when the horses were at different water depths (WDs): DRY = control condition; WD-CAN = mid-cannon bone; WD-RAD = mid-radius; WD-SHOUL = shoulder point. The columns represent the median values of the upward amplitude of the vertical displacement and the lines extending vertically from the column indicate the interquartile range. \* $P$  values < 0.05

**Table 3**—Median differences in the vertical displacement of the trunk in 6 horses when trotting on a water treadmill at 2 speeds (3.5 m/s and 5 m/s) and different water depths (DRY = dry condition; WD-CAN = mid-cannon bone; WD-RAD = mid-radius; WD-SHOUL = shoulder point).

	DRY		WD-CAN		WD-RAD		WD-SHOULD	
	Median (cm)	IQR	Median (cm)	IQR	Median (cm)	IQR	Median (cm)	IQR
Withers								
Up	0.1	[-0.1, 0.3]	-0.8	[-1.2, -0.2]	-1.2	[-1.7, -1.1]	-1.1	[-1.2, -0.9]
Down	0.1	[-0.05, 0.3]	-1.1	[-1.2, -0.2]	-1.2	[-1.3, -1.1]	-1.3	[-1.4, -1.1]
T18								
Up	-0.9	[-1.1, -0.8]*	-2.1	[-2.4, -1.7]*	-1.6	[-2.4, -1.3]*	-1.8	[-2.2, -1.3]*
Down	-0.9	[-1.1, -0.6]*	-1.9	[-2.3, -1.5]*	-1.8	[-2.7, -1.7]*	-1.8	[-2.2, -1.3]*
Tuber sacrale								
Up	-1.3	[-1.8, -1.2]	-1.5	[-1.9, -0.7]	-1.4	[-1.8, -1.2]*	-1.0	[-1.4, -0.2]
Down	-1.2	[-1.3, -1.1]	-1.5	[-1.8, -0.9]	-1.5	[-1.8, -1.1]*	-0.8	[-1.3, -0.4]
S5								
Up	-1.0	[-1.3, -1.0]	-1.3	[-1.5, -1.1]	-0.8	[1.0, 0.6]	-0.3	[-0.5, -0.03]
Down	-0.9	[-1.2, -0.8]	-1.3	[-1.5, -1.2]	-0.7	[-0.8, 0.6]	-0.3	[-0.5, 0.01]

Up: the absolute value of the upward amplitude during the propulsion phase; Down: the absolute value of the downward amplitude during the absorption phase. Data represent the difference between slow (3.5 m/s) and fast (5 m/s) trot, as medians and their interquartile ranges in square brackets.

\* $P$  values < .05.

WD-RAD ( $p = 0.03$ ) (Figure 3). Despite a nonstatistically significant difference at lower (WD-CAN) or higher (WD-SHOULD) water levels, the VD values were lower at these anatomical locations when the trotting speed increased from 3.5 m/s to 5 m/s. At the level of S5, there were no significant changes in the VD amplitude related to the trotting speed ( $P > .05$  for all conditions) (Figure 3).

## Discussion

The present study quantified the vertical trunk movement in sound horses exercising on a water treadmill at the trot. The results show that increasing the water depth up to mid-radius induces an increase in the vertical displacement of the trunk of approximately 2 to 4 cm compared with the dry condition, with the highest values recorded at the level of T18. These findings support the first hypothesis of this investigation and provide further information to previous studies that analyzed only withers<sup>18</sup> and pelvic<sup>18,19</sup> vertical movements in horses trotting on a WT and water up to the carpus.

The thoracolumbar junction was the dorsal segment most affected by the changes in water depth and speed, compared to the cranial thoracic and pelvic area at both mid-cannon and mid-radius water levels. In contrast, a further increase in the water level up to the shoulder did not produce any significant change in the trunk vertical displacement compared to dry, except a small amount of increase at the level of the withers at slow trot. Thus, at the other anatomical locations, the amount of vertical displacement returned to baseline when trotting in deep water, with a significant reduction of the dorsoventral movement compared to water at the radius level.

The vertical trunk movement was previously measured using accelerometers in horses exercising on the WT at the walk<sup>14,21</sup> with quite similar results. Saitua et al (2020) quantified the dorsoventral displacement of the horse's body using 2 sensors placed in the pectoral and sacral regions. This locomotor variable significantly increased as the water moved from dry to carpus level, with no further change when the water reached the stifle height.<sup>21</sup> Tranquille et al (2022) studied the simultaneous change in the limb and back kinematics at the walk related to water depth. The dorsoventral and mediolateral displacements of the sacrum and the left and right tuber coxae were significantly increased as the water depth increased until the carpus level. They interpreted these findings as a compensatory movement pattern of the pelvis when the horse reached the maximal tarsal flexion in response to the increased water level.<sup>14</sup>

The horse usually adapts its locomotion in the presence of water to going forward with a minimal energy expenditure. Consequently, during partial immersion, the horse tries to step over the water surface. This induces several limb and back adaptations, previously demonstrated at the walk using 2- or 3-D kinematics methods.<sup>11,13,16</sup> The horse tries to avoid contact with the water by increasing flexion

and elevation of the distal<sup>11</sup> and proximal<sup>13</sup> joints, and increasing the amount of the thoracolumbar flexion.<sup>16</sup> Similar adaptations of the horse's locomotion were observed in our study at the trot during partial immersion, which could explain part of the results obtained for the dorsoventral displacement of the trunk. However substantial differences related to the gait should be considered. As the trot has a suspension phase, the dorsoventral movement of the trunk is a passive phenomenon related to the abdominal mass displacement during both the stance and swing phases.<sup>22,23</sup> Thus, the increase in the trunk vertical displacement at any sensor location observed in this study in response to low or intermediate water levels should be interpreted as a consequence of the increased inertia of the visceral mass when trotting over the water and the abdomen being not or partially immersed. When the water level is too high and the horse is almost completely submerged, there is no more increase in suspension at the trot, as the buoyancy and hydrostatic pressure limits the vertical excursion of the body mass.

One of the main consequences of the increased dorsoventral movement of the trunk and suspension when trotting in water up to an intermediate level may be the influence on the load supported by the distal joints and the suspensory apparatus during the stance phase. The peak of extension of the metacarpophalangeal joint and the peak strains of the superficial digital flexor tendon and the suspensory ligament at midstance is proportional to the vertical ground reaction force (vGRF).<sup>30,31</sup> As a result of buoyancy, the vGRF and the vertical acceleration decrease proportionally to the increase in the water depth.<sup>6,32</sup> Based on these observations, WT exercise at the trot for horses recovering from a fetlock or suspensory ligament injury should be avoided in acute stage or done in higher water levels. On the other hand, trotting at mid-cannon or mid-radius water depths may be indicated at the chronic stage of the disease, to restore the elasticity of the palmar/plantar tissues. However, further work in this area is warranted to extrapolate other clinical considerations.

Flexion and extension movements of the equine vertebral column at the trot have not been previously studied during immersion, but quantified in sound horses trotting on the track<sup>23,24</sup> and coupled with the electromyographic activity of the trunk muscles.<sup>25-28</sup> These studies demonstrated that the rectus abdominis and the longissimus dorsi muscles are activated at the trot to stabilize the equine spine in response to the dynamic forces produced by the visceral mass inertia during both stance and swing phases. In horses trotting on a dry treadmill at increasing speed, the activity of both *longissimus dorsi* and *rectus abdominis* muscles increased linearly with the speed, leading to a simultaneous reduction of the back range of motion in flexion-extension and of the amount of thoracolumbar flexion.<sup>27</sup> Therefore, similar or higher activation of these muscles can be assumed also when trotting in water at increasing speed, with the most pronounced effects at the level of the thoracolumbar junction as observed in

the present work. Based on these results, trotting in water at increasing speed should not be recommended in horses suffering from chronic back pain, for example, if the aim of the rehabilitation is to restore the range of motion of the vertebral column.

To the authors' knowledge, this is the first study evaluating the locomotion in horses when trotting on a WT in deep water and fast speed (up to 5 m/s). Similarly when walking,<sup>10,11,13,14</sup> the stride frequency at trot decreased as the water depth increased, with the smallest values obtained when the water was at the level of the shoulder, probably due to the increase of the swing phase duration during immersion.<sup>11,13,14</sup> A recent investigation<sup>33</sup> demonstrated that water depth and walking speed have an opposite effect on stride duration, with a 0.2 s reduction for every 1 km/h of increase in speed, but similar increase in stride duration increasing the water depth to the fetlock or the carpus.

Trotting in deep water, even at high speed, induces a need of energy mainly thorough the aerobic metabolism and moderate in intensity, according to a previous study.<sup>8</sup> This type of exercise was well tolerated by the horses of the present study, which were able to maintain a regular and symmetrical gait during the protocol. However, the ability to maintain a correct posture during the session should be considered at this condition. Indeed, the horses may be uncomfortable because of the increased presence of waves at trotting speeds and may increase the head elevation and cervical extension to avoid the contact with the water, as previously observed at the walk. The only study published on electromyography of neck and forelimbs muscles of horses exercising on a WT<sup>29</sup> supports these clinical observations. This study<sup>29</sup> conducted on 6 horses walking and trotting in a water depth of 1.20 m, revealed an increase in the electromyographic activity of the *splenius* muscle at the trot, which is a neck extensor muscle.

The present work has some limitations. Accelerometric data were collected in a population of Standardbred horses and may be difficult to extrapolate to other breeds, selected for show jumping or dressage activity. The data were collected from a small sample size and were not normally distributed, limiting the power of the tests used for the statistical analysis. The use of accelerometric devices allowed to easily collect the data and to overcome the difficulties in applying skin markers in water at trotting speeds. However, this method prevented a simultaneous kinematic analysis of the trunk motion at each spinal segment. The validation of an algorithm to calculate thoracolumbar flexion and extension angles from these accelerometric data is currently underway at our institute.<sup>34</sup> In addition to the vertical displacement of the trunk, it would therefore be possible to evaluate changes in thoracolumbar flexion and extension at trot according to the water depth and speed.

In conclusion, the water depth and speed may have an opposite effect on the dorsoventral movement of the trunk in horses trotting in water with partial immersion of the abdomen. The VD increases

when increasing the WD up to mid-radius, while the VD decreases while increasing the trotting speed, with the main effects on the thoracolumbar junction.

These data measured on sound horses are important for better understanding the effect of WT exercise at trotting speeds and to develop some guidelines for a more controlled use of this modality at this gait as a part of training or rehabilitation protocols in horses.

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## Supplementary Materials

Supplementary materials are posted online at the journal website: [avmajournals.avma.org](http://avmajournals.avma.org)