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Research Article

Haptic contact with a walking dog improves human balance during a quiet tandem task with various levels of difficulty

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HIGHLIGHTS
- Haptic contact with a moving dog helps to reduce postural sway.
- Handling a moving dog, without vision, expands the exploitation of haptic cues.
- With vision, handling a moving dog increased sway as surface height increased.

ABBREVIATIONS

AP	Anterior-posterior
COP	Center of pressure
EC	Eyes closed
EO	Eyes open
ML	Medial-lateral
MSS	Mean sway speed
RMS	Root mean square

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BACKGROUND: When a person walks a dog, information from variables of their own postural control is integrated with haptic information from the dog's movements (e.g., direction, speed of movement, pulling forces).
AIM: We examined how haptic information provided through contact with a moving endpoint (here, the leash of a dog walking on a treadmill) influenced an individual's postural control during a quiet tandem standing task with and without restricted vision and under various elevations of the support surface (increased task difficulty levels).
METHOD: Adults performed a 30-second quiet tandem stance task on a force platform while holding a leash attached to a dog who walked on a treadmill parallel to the force platform. Conditions included: haptic contact (dog and no-dog), vision constraint (eyes open, EO, and eyes closed, EC), and surfaces (4 heights).
RESULTS: Interaction between haptic condition and vision showed that contact with the dog leash reduced root mean square (RMS) and mean sway speed (MSS). RMS showed that the highest surface had the greatest rate of sway reduction during haptic contact with EC, and an increase with EO.
CONCLUSION: The dog's movements were used as a haptic reference to aid balance when eyes were closed. In this condition, contact with the dog's leash reduced the extent of sway variability on the higher surfaces.

KEYWORDS: Dog walking | Human-animal interaction | Haptic contact | Balance tasks | Task constraints

INTRODUCTION

Humans routinely hold, carry, handle, lead, and touch domestic animals such as dogs for various purposes. However, research on their physically-interactive interdependency is a recent endeavor.[1-3] In these human-animal activities, interindividual information exchange occurs symbiotically so that the pair can accomplish various tasks or even react to challenging situations (e.g., a person holding onto a rescue dog to avoid drowning). In other instances, more complex demands for cooperative behavior include the use of tools for *mediating* information, such as when an individual uses a leash to handle a dog during obedience training. The use of dogs to aid mobility or navigation requires that both dog and human bodies are synchronized in posture alignment and common direction.[4,5] Recently, the interaction between dogs and their handlers has fostered great interest in researchers who want to understand dogs' interaction abilities with humans.[1] These studies have inspired the designs of robotic companions as a haptic aid for gait rehabilitation in stroke patients[2] and robotic interfaces for the blind so that they may better navigate independently.[6] The interdependent synchronization between humans and dogs has created an invaluable therapeutic alternative for people with disabilities, particularly those who are blind.[7]

The haptic connection of an individual with another, and even with objects (e.g., an anchor system, light touch of surfaces), illustrates how complex systems and subsystems convey information dynamically to comply with task demands of various types (e.g., walking, standing).[8-15] All of these studies on the use of haptic contact during walking and standing tasks have shown some improvement in balance and stability in motor patterns.

In our previous studies,[16-18] blindfolded participants who handled a dog (via a leash), while simultaneously walking on a balance beam, showed improved gait parameters with corresponding reduced variability. Previous research has shown that adults tethered via a hand-held leash to a walking dog[16,17] improved balance when vision was not available. Some of these studies[16,17] included preliminary results of the human-dog interaction tasks investigated here. A positive postural outcome was also observed for individuals with intellectual disability, who typically present balance difficulties.[16]

Taking a dog for a walk is an interconnected task context in which both individuals, human and dog, perform a similar type of movement (e.g., walking), and illustrates how a continuous exchange of haptic information serves both individuals in carrying out their performances. Also, types of human-dog activities in which each of the individuals performs a distinct task simultaneously (e.g., an individual riding a bike or balancing on a skateboard while tethered to his walking or running dog) illustrates an interconnected task context with haptic cue exchanges. In both cases, potential solutions arise even when unpredictable movements occur. Keeping the body still while a companion dog moves (i.e., walks on a treadmill) provides an experimental context to investigate how the human haptic system integrates relevant information from a distal and somewhat unpredictable source, yet it can aid the postural system while it carries out a separate motor task (e.g., quiet stance). Furthermore, other studies using haptic tasks (e.g., light touch, haptic anchoring) have demonstrated that the postural task itself has to be challenging enough (e.g., unstable surfaces, vision occlusion) so that an individual can better exploit the haptic information of an external source to serve the postural task.[19]

Our main question here was, “How do individuals use the dynamics of a perturbed extrinsic task context (i.e., exposure to the potentially unpredictable behavior of a leashed dog walking on a treadmill) as haptic input to improve their balance during a standing postural task? Also, does this dynamic haptic interdependency affect the human postural outcome as the task’s difficulty escalates (i.e., various height surface elevations)?” Therefore, we had two objectives. First, we assessed how haptic information, provided through contact with a moving endpoint (i.e., a dog walking on a treadmill), influences the control of posture. We used restricted vision (intrinsic constraint) during a quiet tandem standing task to assess how haptic information affected individuals’ balance control while simultaneously performing the haptic task. Second, we investigated the influence of the haptic information provided by a moving endpoint on the postural task performance at different height surface elevations (extrinsic constraints).

For the first objective, we hypothesized that the haptic cues provided by a moving dog would be integrated into a balance task only when vision is not available. For the second, we hypothesized that manipulating the surface height would increase task difficulty and cause greater balance sway. Therefore, our expectation was to find an interaction (in both postural sway displacement and speed) between vision, height surface, and dog contact. We hypothesized that vision would be sufficient to compensate for the potential challenges of the surface; however, because vision would compensate for the surface challenge, the dog would not be used as a haptic aid. However, without vision in the dog condition, we expected that as surface challenges increased, these effects would be compensated for (i.e., improved balance) by the haptic cues provided via the connection to the dog.

METHODS

Participants

Healthy young adults (*n*=20, four males, 24.5±5.6 years, BMI 23.6±3.6 kg/m^2) volunteered for this study. Four participants were left-handed. The guardian of Polar, a six-year-old female Akita, permitted the dog to participate in the study as the haptic contact endpoint mechanism. In addition to having treadmill walking experience and familiarity with the lab staff, the dog had been trained in regular obedience training.

The university's Research Ethics Committee for humans (#1024/2012) and animals (#1841/2012) approved the study. Exclusion criteria included any self-reported neurological, vestibular, or musculoskeletal conditions that might affect balance, fear of dogs, and visual problems not corrected by glasses or lenses.

Procedure

Participants stood still for approximately 40 seconds on a force platform (50×50 cm, AccuGait, AMTI Systems, USA) with their feet in a tandem position (i.e., one foot in front of the other, with toes of the rear foot touching the heel of the forefoot). The dominant foot was placed in the front position and determined by asking participants to mimic which foot they preferred while kicking a ball. Data acquisition was set at 120 Hz for 30 seconds.

An "adaptation window" of 8-10 seconds of practice just before the silent triggering of the 30-second data collection recording was given for each trial. Participants were unaware of when the data recording was triggered. The decision to start the data recording was based on the principal researcher's visual inspection of the participant's body and feet positioning and a satisfactorily steady postural response. This included the participant's ability to stand independently past the initial 8-10 seconds (with no need for touch or verbal encouragement from the security person) while simultaneously having complete control of the leash attached to the walking dog.

The first half of the recruited participants performed the tasks with the dominant hand and the remaining half with the non-dominant. We found no statistical differences between these sub-groups, so we decided not to include hand dominance as a factor in our statistical models.

Participants performed two haptic contact conditions (i.e., without and with the dog), two vision conditions (i.e., eyes open [EO] and eyes closed [EC] and covered with a blindfold), and four height surfaces (i.e., ground level, 10-cm, 20-cm, and 30-cm balance beam), totaling 16 experimental conditions. For the dog condition, participants held a leash with the opposite end attached to the dog. The dog walked on a treadmill (Total Health Brazil LTDA; Figure 1) set at 2 km/h. The dog was trained to walk on the treadmill and respond to leash commands (e.g., keep walking and maintain a straightforward direction). In the conditions without the dog, the treadmill was turned off and the participants released the leash while the dog remained in place waiting for further trials. In the EO condition, participants looked forward toward an orange circle (10-cm diameter) placed at eye-height on a white background and located at a 200-cm distance from the force platform. The balance beam (9 cm wide × 70 cm long × 10 cm high) was centered on the force platform. The extra 20 cm length portion of the balance beam stretched outwards freely (at approximately equal 10-cm lengths in the front and back of the force platform's surface). To raise the balance beam for the 20- and 30-cm height surfaces, wood supports (10 cm wide x 20 cm long x 10 cm high) were placed under the balance beam to achieve the appropriate heights. Participants performed each condition twice, in sequence. All experimental conditions were completely randomized.

Figure 1. Experimental layout of the DOG condition, with the participant connected via leash to a dog walking on a treadmill and keeping a quiet tandem stance on a 10-cm balance beam. (Note: the assistant who held the second leash, although present, is hidden from this view's angle.)

In the dog conditions, participants were instructed about moving the leash's position and pulling subtly on it to prevent the dog from destabilizing while walking. The choice of attaching the leash to the dog's collar was based on the dog's conditioning to walking with a leash in this manner. Participants were instructed to keep the leash "relatively tight"; that is, firm, but not so tight as to upset or pull the dog off the treadmill. A second leash was held by an assistant (hidden from view in Figure 1) positioned in front of the dog to facilitate the dog's compliance in the task and for safety measures (i.e., to prevent the dog from abandoning the task and causing the participant to fall in the EC conditions). In the EO conditions with the dog, this second experimenter was partially within the participants' peripheral view field. We did not account for potential interference from this context; therefore, it should be considered a limitation of the study. The dog could turn her head or slightly advance or lag on the treadmill belt. The second leash was not used to pull the dog and was left loose when the dog's compliance was deemed adequate. We were prepared to interrupt and repeat the trials if any disruptions from the dog occurred. The second leash handler delivered whispered verbal encouragement and very subtle pulls on the leash to prevent unpredictable movements from escalating. We had only two occasions when a trial was suspended and resumed, and neither was caused by the dog's performance.

At the end of the session, participants were asked whether they had experienced discomfort, distractions, or trouble with the experimental design, including dog handling. They had not.

Data analysis

The force plate software computed the coordinates of the center of pressure (COP). We filtered these coordinates with a 4th-order Butterworth low-pass filter with a cut-off frequency of 5 Hz. We calculated the root mean square (RMS) and the mean sway speed (MSS) of the COP in the anterior-posterior (AP) and medial-lateral (ML) directions.

Statistical Analyses

We used the mean value of the two trials for statistical analysis. For the first purpose, we used a two-way multivariate analysis of variance (MANOVA; 2 haptic contact conditions [without and with the dog] x 2 vision conditions [EO and EC]), with repeated measures in the last two factors. In these analyses, the dependent variables were the RMS and MSS in the ground level condition. For the second aim, we employed a three-way MANOVA (2 haptic contact conditions [without and with the dog] x 2 vision conditions [EO and EC] x 3 heights [10-cm, 20-cm, and 30-cm]), with repeated measures in all factors. We ran separate MANOVAs for each dependent variable, combining the AP and ML directions. Univariate tests followed each MANOVA. Post-hoc analysis with Bonferroni adjustment followed the univariate tests to identify the differences for the main and interaction effects. The level of significance was $p<0.05$.

RESULTS

Part 1: The haptic dog contact effect

The MANOVA exhibited an interaction between vision and haptic contact (Table 1) in both RMS and MSS. The univariate analysis identified the interaction in the ML direction for the RMS and in both directions for the MSS. The dog contact reduced the RMS in the ML direction, but only with EC (p=0.003, Figure 2). For the MSS in the AP direction, the dog contact increased sway speed with EO (p=0.019), but there was no effect with EC. In the ML direction, dog contact reduced MSS with EC (p=0.003) but not with EO (Figure 2).

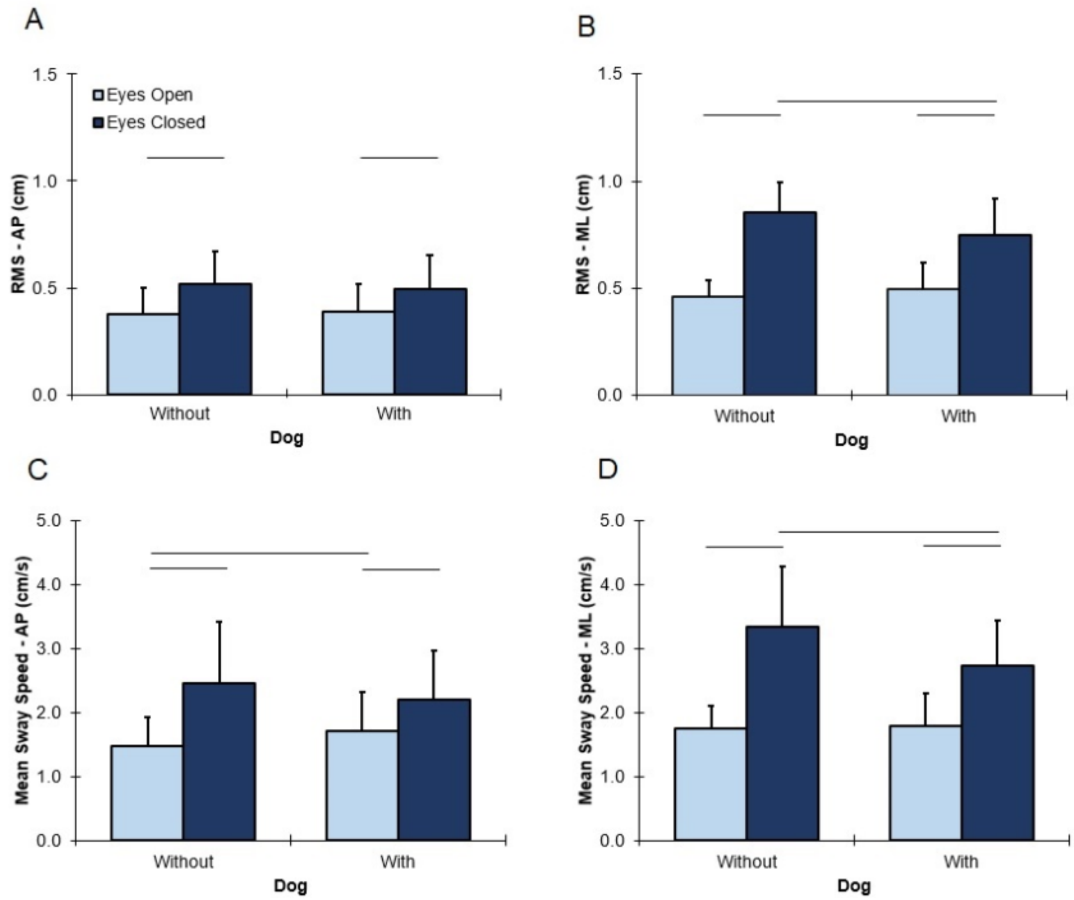

Figure 2. Mean and standard deviation of the root mean square (RMS) AP (A), RMS ML (B), mean sway speed (MSS) AP (C), and MSS ML (D) for the postural task, without and with the haptic dog contact, with eyes open (EO) and eyes closed (EC). Horizontal lines indicate the pairwise differences (see text for exact *p*-values).

Table 1 – *F*- and *p*-values for the main and interaction effects of dog contact and vision of the MANOVA and the univariate follow-up for the postural control variables. Bold *p*-values indicate statistical significance. (AP: anterior-posterior | ML: medial-lateral | RMS: root mean square | MSS: mean sway speed)

Variables	Contact condition		Vision condition		Contact * vision conditions	
MANOVA						
RMS	Wilks' λ=0.885, $F_{2,18}$=1.166, *p*= .334; ^{2}= .115		Wilks' λ=0.100, $F_{2,18}$=81.412, ***p*≤ .0001;** ^{2}= .900		Wilks' λ=0.480, $F_{2,18}$=9.740, ***p*= .001;** ^{2}= .520	
MSS	Wilks' λ=0.629, $F_{2,18}$=5.310, ***p*= .015;** ^{2}= .371		Wilks' λ=0.076, $F_{2,18}$=108.660, ***p*≤ .0001;** ^{2}= .924		Wilks' λ=0.585, $F_{2,18}$=6.393, ***p*= .008;** ^{2}= .415	
Follow-up univariate	AP	ML	AP	ML	AP	ML
RMS	$F_{1,19}$=0.75, *p*= .787 ^{2}= .004	$F_{1,19}$=2.307, *p*=*.145* ^{2}= .108	$F_{1,19}$=28.263, ***p*≤ .0001** ^{2}= .598	$F_{1,19}$=156.674, ***p*≤ .0001** ^{2}= .892	$F_{1,19}$=.982, *p*= .334 ^{2}= .049	$F_{1,19}$=16.009, ***p*= .001** ^{2}= .457
MSS	$F_{1,19}$=0.037, *p*= .850 ^{2}= .002	$F_{1,19}$=6.771, ***p*=*.018*** ^{2}= .263	$F_{1,18}$=57.908, ***p*≤ .0001** ^{2}= .753	$F_{1,19}$=145.885, ***p*≤ .0001** ^{2}= .885	$F_{1,19}$=7.506, ***p*= .013** ^{2}= .283	$F_{1,19}$=13.463, ***p*= .002** ^{2}= .415

Part 2: Surface height difficulty and the haptic dog contact

The MANOVA showed a triple interaction for the RMS (Table 2), and the univariate tests identified this interaction only in the ML direction. At all three heights, the dog contact reduced RMS, but only with EC (10-cm: p=0.004, 20-cm: p≤0.0001; 30-cm: p≤0.0001, Figure 3). With EO, the dog contact increased RMS at the 20-cm (p≤0.0001) and 30-cm (p=0.002) heights (Figure 3).

For both RMS and MSS, the MANOVAs exhibited interaction between haptic contact and vision (Tables 2 and 3). The results of these interactions corroborated the findings of the first part of this study. For the MSS, there was a main effect of height in AP and ML directions (Table 3); however, despite the increase in MSS with height increase, dog contact did not interact with height.

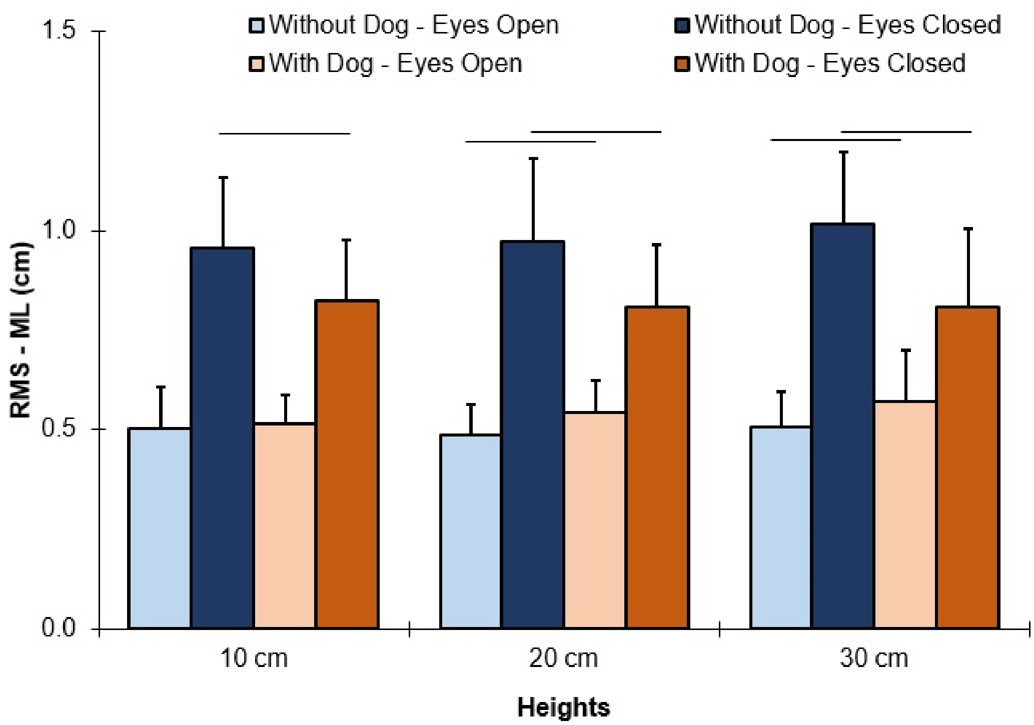

Figure 3. Mean and standard deviation of the RMS in the ML direction, without and with dog contact (haptic contact), with eyes open (EO) and eyes closed (EC) at each surface height. Horizontal lines indicate the pairwise differences (see text for exact p-values).

Table 2 – *F*- and *p*-values for the main and interaction effects of dog contact, vision, and surface height of the MANOVA and the univariate follow-up for root mean square (RMS). Bold *p*-values indicate statistical significance. (AP: anterior-posterior | ML: medial-lateral)

Variables	Contact condition	Vision condition	Height condition
MANOVA	Wilks' λ=0.617, $F_{2,18}$=5.595, ***p*= .013**, ^{2}= .383	Wilks' λ=0.048, $F_{2,18}$=178.873, ***p*≤ .0001**, ^{2}= .952	Wilks' λ=0.814, $F_{4,74}$=2.009, *p*= .102, ^{2}= .098

RMS	Interactions			
	Contact vs. vision	*Contact vs. height*	*Vision vs. height*	*Contact vs. vision vs. height*
	Wilks' λ=0.294, $F_{2,18}$=21.614, ***p*≤ .0001**, ^{2}= .706	Wilks' λ=0.969, $F_{4,74}$=0.291, *p*= .883, ^{2}= .016	Wilks' λ=0.810, $F_{4,74}$=2.052, *p*= .096, ^{2}= .100	Wilks' λ=0.763, $F_{4,74}$=2.673, ***p*= .038**, ^{2}= .126

Follow-up univariate	Contact condition		Vision condition		Height condition	
	AP	ML	AP	ML	AP	ML
RMS	$F_{1,19}$=1.222, *p*=.283, ^{2}= .060	$F_{1,19}$=9.895, ***p*= .005**, ^{2}= .342	$F_{1,19}$=77.025, ***p*≤ .0001**, ^{2}= .802	$F_{1,19}$=242.302, ***p*≤ .0001**, ^{2}= .927	$F_{2,38}$=4.111, ***p*= .024**, ^{2}= .178	$F_{2,38}$=1.762, *p*= .185, ^{2}= .085

RMS	Interactions							
	Contact vs. vision		*Contact vs. height*		*Vision vs. height*		*Contact vs. vision vs. height*	
	AP	ML	AP	ML	AP	ML	AP	ML
	$F_{1,19}$=22.896, ***p*≤ .0001**, ^{2}= .546	$F_{1,19}$=45.082, ***p*≤ .0001**, ^{2}= .704	$F_{2,38}$=0.312, *p*= .734, ^{2}= .016	$F_{2,38}$=0.274, *p*= .762, ^{2}= .014	$F_{2,38}$=2.276, *p*= .117, ^{2}= .107	$F_{2,38}$=0.036, *p*= .964, ^{2}= .002	$F_{2,38}$=1.668, *p*= .202, ^{2}= .081	$F_{2,38}$=5.714, ***p*= .007**, ^{2}= .231

Table 3 – *F*- and *p*-values for the main and interaction effects of dog contact, vision, and surface height of the MANOVA and the univariate follow-up for the mean sway speed (MSS). Bold *p*-values indicate statistical significance. (AP: anterior-posterior | ML: medial-lateral)

Variables	Contact condition	Vision condition	Height condition
MANOVA	Wilks' λ=0.635, $F_{2,18}$=5.177, ***p*= .017**, ^{2}= .365	Wilks' λ=0.088, $F_{2,18}$=92.838, ***p*≤ .0001**, ^{2}= .912	Wilks' λ=0.584, $F_{4,74}$=5.707, ***p*≤ .0001**, ^{2}= .236

MSS	Interactions			
	Contact vs. vision	*Contact vs. height*	*Vision vs. height*	*Contact vs. vision vs. height*
	Wilks' λ=0.374, $F_{2,18}$=15.052, ***p*≤ .0001**, ^{2}= .626	Wilks' λ=0.903, $F_{4,74}$=0.971, *p*= .428, ^{2}= .050	Wilks' λ=0.817, $F_{4,74}$=1.969, *p*= .108, ^{2}= .096	Wilks' λ=0.837, $F_{4,74}$=1.721, *p*= .154, ^{2}= .085

Follow-up univariate	Contact condition		Vision condition		Height condition	
	AP	ML	AP	ML	AP	ML
MSS	$F_{1,19}$=4.536, ***p*= .046**, ^{2}= .193	$F_{1,19}$=9.210, ***p*= .007**, ^{2}= .326	$F_{1,19}$=100.608, ***p*≤ .0001**, ^{2}= .841	$F_{1,19}$=185.299, ***p*≤ .0001**, ^{2}= .907	$F_{2,38}$=13.201, ***p*≤ .0001**, ^{2}= .410	$F_{2,38}$=8.550, ***p*= .001**, ^{2}= .310

MSS	Interactions							
	Contact vs. vision		*Contact vs. height*		*Vision vs. height*		*Contact vs. vision vs. height*	
	AP	ML	AP	ML	AP	ML	AP	ML
	$F_{1,19}$=31.640, ***p*≤ .0001** ^{2}= .625	$F_{1,19}$=26.572, ***p*≤ .0001** ^{2}= .583	$F_{2,38}$=1.813, *p*= .177 ^{2}= .087	$F_{2,38}$=0.662, *p*= .522 ^{2}= .034	$F_{2,38}$=2.886, *p*= .068 ^{2}= .132	$F_{2,38}$=0.530, *p*= .593 ^{2}= .027	$F_{2,38}$=3.033, *p*= .060 ^{2}= .138	$F_{2,38}$=3.154, *p*= .054 ^{2}= .142

DISCUSSION

Our study assessed how the haptic information from a moving endpoint (i.e., a dog walking on a treadmill) influenced posture control during a quiet tandem standing task. We first analyzed the effect of vision (EO and EC) to assess the extent of the influence of an intrinsic constraint to the haptic task (i.e., contact with the dog). Second, we evaluated whether degrees of increased postural task difficulty of surface of various heights (extrinsic constraints) would influence posture control solutions during the haptic contact with the dog.

The moving dog conveys haptic information for postural control

In the first part of the study, we found that the availability of vision during contact with the dog did not affect the status of balance by reducing sway. Postural sway and speed, however, decreased significantly when the haptic task was performed with EC. Therefore, we confirmed our first hypothesis, which stated that the haptic cues of a moving dog would be integrated into a balance task only when vision was not available.

We assume that, in the absence of vision, sensory cues from the hand (e.g., skin, joints, and muscle) in contact with the leash can integrate invariant aspects of the material and forces of the dog's motion that pull in various directions, therefore, converting valuable haptic information to aid the postural control system.[20] When vision was available, the postural task appeared to be controlled independently of the haptic task, even though they occurred simultaneously. The haptic task, in this case, was carried out as a separate one, and any need for postural correction by the postural control system would rely on the visual cues as the primary source of information. Indeed, vision has a dominant effect on the postural control system, and it helps to overcome disruptions. One interesting result was the increase in sway speed in the AP direction during contact with the dog, with EO. This result could indicate a disruption--from handling the dog--to the standing task. With EO, participants were free to adjust their arm to the dog's movements, independent of their body oscillation. Although the dog was trained to satisfactorily perform the task and was relatively constrained in the task space, there was some latitude for disruptions such as lagging or deviating her foot placement on the treadmill. The higher sway speed of the participants' body in the AP direction during dog contact and with EO could result from changes in the optical flow caused by the peripheral view of the walking dog. We did not control for kinematic changes of the participant, nor of the dog, to objectively account for these possibilities.

Vision is often experimentally obstructed or manipulated to assess the effect of somatosensory (i.e., muscle, tendons, etc.) and haptic inputs (i.e., the action-perception mechanism involved in the detection of mechanical forces imprinted on tissues, organs, or the whole organism during an action) on balance during postural tasks or locomotion tasks. Haptic information helps an individual develop strategies to achieve a task successfully, but requires voluntary decisions about and, often, awareness of the task's state of continuous change (i.e., supra-postural mechanism).[21-23]

Our results support previous findings related to haptic contact during walking and standing tasks that employed dogs.[16,18] The interdependence between sources of constraints (e.g., blindly handling the leash and the motion of the dog's neck and body during locomotion) expands the biological boundaries of information pickup and reorganizes both organisms' configurations—human's and dog's—via their haptic systems to support behavioral tasks (e.g., standing still). This expansion of biological boundaries travels over surfaces and throughout appended objects (rigid and non-rigid). This is observed, for example, when individuals haptically handle soft objects, as demonstrated in studies using the anchor paradigm.[3,24] An anchor system includes haptic contact to a distal endpoint using a soft portion of an object (e.g., a flexible cable connected to a mass, or anchor). This mechanism illustrates how individuals actively explore solutions by detecting the spatiotemporal information patterns of a (quasi-) stable tool-environment or moving tool-environment relationship.[16] Although we did not measure pulling tension levels on the dog's leash, we anticipate that excessive mechanical pull would negatively compromise the dog's walking task and prevent the participant from probing with the leash for spatial orientation cues.

Haptic information affects body sway according to surface height elevation

The second part of our study demonstrated that, overall, surface height elevations posed a challenge to the postural system, regardless of contact with the dog. When participants were connected to the dog and blindfolded, the surface contexts did not affect how participants exploited the haptic cues from the dog contact. Although there was a distinct difference in the balance outcomes relative to the condition without the dog, their extent was relatively the same throughout the surfaces (MSS variable, AP and ML). However, for RMS-ML, differences increased as surface height increased. This result partially agrees with our second hypothesis (i.e., in the dog condition without vision, as surface challenges increase, their effects could be compensated for [i.e., improved balance] via the haptic cues from the dog connection).

Holding the leash with EO increased the RMS for the two highest surface elevations. This result means that, with EO, the dog condition was a disruptive context for the postural system. Therefore, our hypothesis that vision would be sufficient to compensate for the potential challenges of surface (i.e., showing a similar extent of sway) was partially rejected because balance deterioration increased for the two highest surfaces. The additional task's level of difficulty from the surface height elevations appears to influence the individual's optimal use of haptic information.

In this study, EC was already a difficult task context during the haptic contact with the dog. A previous study that used the haptic contact design with a dog showed that individuals who walked on a balance beam with the dog at their side improved various gait parameters only when blindfolded.[18] Similar results were found during the same experimental protocol with adults with intellectual disability.[16] An easy postural task demand results in little or no effect during haptic tasks (e.g., light touch, anchoring, dog handling).[19,25]

Increased levels of difficulty in balance tasks—particularly when sensory deprivation is manipulated together with degrees of task difficulty—demand successful solutions for a variety of reasons. The first is the fear of falling. Mauerberg-deCastro et al.[26] observed that adults with intellectual disability, when using an anchor system, better exploited higher support surfaces—although they cause increased levels of body sway. In our study, the contact with the dog, and EC, was a task context with similar outcomes, regardless of surface heights. A challenging surface demands attention to the task, with more focus on the haptic task. However, an outcome's success is relative. In the context of contact with the dog and no vision, as the surface heights increased, the unaltering sway perhaps means that a steady optimal behavioral state was achieved and remained unaffected (i.e., a ceiling effect) by these task contexts.

Overall, a less-demanding balance task can impair the haptic system's readiness for exploiting strategies. Costa et al.[25] demonstrated that young and older adults exhibited similar performance in tandem walking—on level ground and on a slightly-raised balance beam—while using the anchor system, even though the older adults exhibited overall poorer performance when compared to the younger adults. They assumed that, even though the older adults showed difficulties with the walking task, their walking pattern was typical for their age and that, perhaps, the degree of difficulty was overestimated in the experimental design. Magre et al.[19] demonstrated through “light touch” that the less difficult the balance task, the poorer the use of haptic cues.

When balance is lost, a series of automatic postural responses occur, and the control system’s goal is to bring back the whole body to an upright position. As a balance task increases in its challenges, emotional factors add complexity to the control system. In order to operate in concert to help maintain an upright and stable body position, the haptic system deals with integrating the automatic postural responses and the intentional control mechanisms derived from exploratory behavior (i.e., when using appendices, such as an anchor system or a leashed dog) in a single, simple solution (e.g., the coordinated behavior alliance between a dog and her master). For instance, in our study, the dog could be susceptible to receiving subtle haptic cues from the second handler’s leash (see Method). However, any impact on the participant’s performance, although possible, would be difficult to control for, or even to measure, as a separate/additional haptic cue. The postural solution is a singular one, which is represented by the sway parameters we measured. This human-dog task context is a simple human behavior (i.e., standing still), whose architecture elegantly spans across malleable links (or, assembled connections) between intrinsic and extrinsic sources of constraints (i.e., the human body, the leash, the dog’s moving body, the support surface, the treadmill motion, etc.) in a (not completely predictable moment-to-moment, but neither completely random) state of flow.[3]

CONCLUSION

The dog walking context seems to have provided opportunities for the exploratory system to fine-tune its search for postural solutions. We concluded that the haptic information mediated through the leash was helpful to the postural system, revealed in its reduced sway. However, this was true only when vision was obstructed, supporting earlier findings that haptic effects seem to rely on task complexity. Furthermore, tasks with increased difficulty, created through the elevation of surfaces combined with vision occlusion, resulted in similar sway outcomes. Conversely, when surface manipulation was combined with vision, the handling of the dog progressively disrupted sway as surface heights increased.

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