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► **To cite this version:**

Lina S Hansson, Julie Lasselin, Arnaud Tognetti, J. Axelsson, M.J. Olsson, et al.. The walking sick: Perception of experimental sickness from biological motion. *Brain, Behavior, and Immunity*, 2023, 113, pp.319-327. 10.1016/j.bbi.2023.07.020 . hal-04199560v2

HAL Id: hal-04199560

<https://hal.science/hal-04199560v2>

Submitted on 13 Nov 2023

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The walking sick: Perception of experimental sickness from biological motion

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ARTICLE INFO

Keywords:

Sickness detection
Biological motion
Point-light displays
Lipopolysaccharide
Experimental endotoxemia

ABSTRACT

Identification of sick conspecifics allows for avoidance of infectious threats, and is therefore an important behavioral defense against diseases. Here, we investigated if humans can identify sick individuals solely from biological motion and posture (using point-light displays). Additionally, we sought to determine which movements and sickness parameters would predict such detection. We collected video clips and derived point-light displays (one stride presented in a loop) of sick walkers (injected with lipopolysaccharide at 2.0 ng/kg body weight) and the same walkers when healthy (injected with saline). We then presented these displays to two groups, one group classified each walker as sick or healthy (study 1, $n = 106$), and the other group scored the walkers' health on a visual analogue scale (study 2, $n = 106$). The raters were able to identify sick individuals above chance, and rated sick walkers as having worse health, both from observing video clips and point-light displays. Furthermore, both sickness detection and worse apparent health were predicted by inflammation-induced increase in rigidity and slower walking, but not other cues. Altogether, these findings indicate that biological motion can serve as a sickness cue, possibly allowing humans to identify sick conspecifics from a distance, and thereby allowing for disease avoidance.

1. Introduction

There are many benefits to living in a social group (Clutton-Brock, 2021), but being around others also comes with the potential cost of being close to pathogens they may carry (Hart and Hart, 2021). In the face of high risk of infections, social species have developed different behavioral strategies to decrease the risk of disease transmission (Hart and Hart, 2021; Schaller et al., 2015), many relying on the ability to detect sickness in conspecifics. Such detection can enable animals to avoid, minimize contact with, or socially exclude the presumably sick individual (Hart, 1990; Stockmaier et al., 2021).

The ability to detect sickness in conspecifics has been demonstrated in various social animals such as termites (Cremer et al., 2007), lobsters (Behringer et al., 2006), mice (Renault et al., 2008), and apes (Poirotte et al., 2017). Humans can use body odor (Olsson et al., 2014) or facial appearance (Axelsson et al., 2018; Arshamian et al., 2021) to discriminate sick from healthy peers. These perceptual cues require that the

observer is relatively close to the sick individual (Gerhardsson et al., 2015). Following the framework of sickness detection as a behavioral first line of defense towards disease transmission (Schaller and Park, 2011), it would be favorable if the detection could occur at a safe distance from a contagious individual, for instance from the way they walk (which can be perceived up to 1000 m, Thornton et al., 2014). We previously tested this notion in a pilot study, in which naïve observers rated the health of moving individuals that had been filmed when they were healthy and when they had been made sick using an intravenous injection of bacterial endotoxin (lipopolysaccharide (LPS), 0.8 ng/kg of body weight) (Sundelin et al., 2015). Results showed that sick walkers were perceived as having worse health compared to the same walkers when healthy, and that perception of worse health was associated with a slower walking speed. However, the study was limited to a few individuals, and it is also possible that facial cues were part of the health assessment since the faces were visible in the video recordings. Consequently, these findings need to be replicated without these limitations to

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<https://doi.org/10.1016/j.bbi.2023.07.020>

Received 6 February 2023; Received in revised form 9 June 2023; Accepted 25 July 2023

Available online 28 July 2023

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determine whether sickness can be detected solely from gait and posture.

The ability to detect actions of moving animals is known as biological motion perception (Johansson, 1973). This is a crucial skill, since movement improves object recognition and holds a vast amount of information, allowing animals to detect and predict behavior of predators, but also individuals in their social context (Troje, 2008). Biological motion perception can be studied with point-light displays (PLDs), i.e., light points placed on an individual's joints (Johansson, 1976, 1973). The observer then relies on motion perception without any additional visual cues (e.g., facial expressions or clothing). PLDs can reveal relevant social information about the moving individual, such as sex (Kozlowski and Cutting, 1977), emotional state (Dittrich et al., 1996), and whether it is someone you know (Cutting and Kozlowski, 1977). Given this fine-tuned ability to obtain information from biological motion, we hypothesized that inflammation-induced sickness could also be detected from biological motion (i.e., from PLDs) without other cues.

The notion that motion can reveal sickness is supported by the fact that sick animals typically move less (Hart, 1988). Similarly, acute inflammation-induced sickness in humans has been, as noted above, associated with slower walking speed (Sundelin et al., 2015). In a recent study, we specified objective sickness-induced changes in human gait and posture using a Kinect® camera (Lasselín et al., 2020b). Individuals made sick with LPS walked with more rigid movement (i.e., less knee flexion and less arm extension), and with the head tilting more downwards, compared to the same individuals when healthy. Furthermore, in accordance with the previous study (Sundelin et al., 2015), they had an overall slower walk. These alterations in gait patterns were predicted by stronger sickness symptoms, lower body temperature, and higher levels of inflammatory cytokines (Lasselín et al., 2020b). Interestingly, these changes in biological motion are similar to those observed in some non-acute medical conditions, such as depression (Adolph et al., 2021; Michalak et al., 2009) and chronic fatigue syndrome (Paul et al., 2008). However, it is still unclear to what degree changes in gait contribute to how humans perceive sickness in others.

In the current study, we aimed to determine whether sickness can be detected by other humans solely from biological motion and posture (i.e., from PLDs). We used video recordings (to replicate previous findings (Sundelin et al., 2015) but without presenting facial cues), and PLDs from walking individuals, once when sick after an intravenous injection of a bacterial endotoxin and once when healthy after a saline injection. We used these visual stimuli in two studies where naïve participants rated the walkers as sick or healthy (study 1), and another group of naïve participants rated apparent health of the walkers on a visual analogue scale (study 2). We hypothesized that participants would successfully identify sick walkers from video recordings as well as from PLDs, and that they would rate walkers in the sick condition as less healthy than when in the healthy condition. We also investigated how well specific gait and posture alterations (i.e. stride parameters and angle of the head, knees, and arms) and sickness responses (sickness symptoms, interleukin-6 concentration, pain, and body temperature) predicted sickness detection and change in apparent health.

2. Methods

2.1. Collection of stimuli

Stimuli were collected in a study investigating subjective and objective behavioral changes during acute inflammation. The study from which the stimuli were obtained was approved by the regional ethical review board in Stockholm, Sweden (Dnr 2015/1415-32) and was preregistered (ClinicalTrials.gov identifier: NCT02529592; see (Lasselín et al., 2017; Lasselín et al., 2020b) for more details on the protocol). In a crossover design, 22 healthy volunteers carried out a walking task on two occasions, once when experimentally made sick after an intravenous injection of LPS (*Escherichia coli* endotoxin, Lot

H0K354, CAT number 1235503, United States Pharmacopeia, Rockville, MD, USA) at 2.0 ng/kg of body weight, and once remaining healthy after an injection of saline (0.9% NaCl). The two occasions were separated by 3–4 weeks, in a counterbalanced order between subjects. The individuals were between 19 and 34 years of age, without any psychiatric or physiological disorders, and not using any medications (except for contraceptive pills). They were all non-smokers, in a healthy weight range, and without excessive alcohol consumption. Video clips and PLDs from 5 individuals were missing or could not be used (see details below). Consequently, stimuli from 17 individuals (7 women, average age: 23.3 ± 2.9 years) were included in the present study.

A walking task was conducted 2–2.5 h after the injection. The variation in starting time was due to a slightly delayed starting time in a few individuals with strong symptoms (i.e., nausea and dizziness). During the task, individuals were asked to walk back and forth five times (i.e., five series) between a start position and a turn position. At the turn position, a GoPro® camera (GoPro, San Mateo, CA, USA) and a Kinect® camera (Microsoft, USA) were placed. Both cameras were placed 75 cm above the ground with a 5.5 m distance to the start position. The individuals were instructed to walk naturally and to look straight forward. In addition, they were told that they could sit down and rest at any moment if needed. Walkers wore pants, socks and white t-shirts during the task.

The Kinect® camera and two Microsoft® programs (Software Development Kit v1.8 and Visual Studio Express) were used to capture the 3-D measurements needed to create the PLDs. The 3-D measurements consisted of 20 joints recorded at ~30 Hz. In addition, the GoPro® camera was used to record regular videos at ~60 Hz. Additional information about the task and the recordings can be found in a previous paper (Lasselín et al., 2020b).

2.2. Processing of stimuli

Among the 22 participants, five walkers were excluded from the present study: biological motion data was not obtained for two individuals due to technical errors; one individual had loose fitting clothes that prevented reliable capture of motion data; two individuals missed video recordings from one of the study days due to logistic reasons.

Video clips. Each series (one series = one back and forth) was cut so that every video clip started with the walker initiating the first step towards the camera and ended before the forehead was no longer fully visible. Hence, the video clips varied in length (2–9 s). Series in which the walker did not move straight or performed additional movements not part of normal walking (e.g. scratching head) were excluded. To standardize the background (e.g. remove a blanket on a chair) and to only show the walking path, 85% of the video image was cropped vertically, i.e. 15% of the original image was shown. The face and hair of each walker was blurred to avoid the influence of facial and hair cues. If an individual was reflected by a nearby glass surface, the reflection was likewise blurred. Video editing was conducted in Adobe Premiere Pro CC®. Video clips were converted from 60 Hz to 30 Hz to reduce file sizes.

Point-light displays. To create PLDs, 3-D coordinates recorded with the Kinect® camera were used. Data from the four joints representing hands and feet were removed due to apparent unreliability (visually not stable). Consequently, data from the 16 remaining joints were used for the PLDs (see Fig. 1). PLDs were created with the Biomotion toolbox (van Boxtel and Lu, 2013) for MATLAB®. One full stride was extracted from the part of the series when the walker moved towards the camera and was in the range of detection of the Kinect® camera (1.2–3.5 m); and was looped. Series were excluded if there were difficulties in creating a smooth loop or if there were unnatural/twitching movements of the joints in the loop. PLDs were extracted from MATLAB® using the program OBS studio®. The loop duration of the PLD was adjusted to the time of the corresponding video clip (from the same series) in Adobe Premiere Pro CC®.

Previous studies have shown better accuracy in biological motion

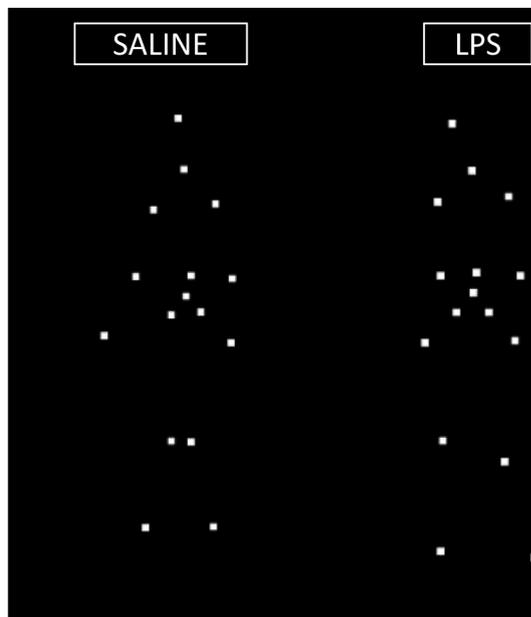


Fig. 1. Two snapshots of PLDs shown from a 45-degree angle illustrating the same walker after an injection of saline (left) and a LPS injection (right). Please follow the link to see the PLDs in motion: <https://osf.io/8dyck/files/osfstorage/63972c8b58abfd06a172fccc>.

detection when the PLD is moving towards the observer compared to in a profile view (Alaerts et al., 2011; Troje et al., 2005). However, it is possible that some of the previously observed sickness-induced gait and posture changes (Lasselien et al., 2020b) would be easier to detect if not walking straight towards the observer (e.g., head tilting more downwards). To determine which angle to use, we conducted a pilot study in which 15 individuals rated the walking speed of eight walkers presented in video clips, PLDs displayed from the front (PLD0°), and PLDs displayed with a 45° angle (PLD45°) on a visual analogue scale. Results showed that ratings from both PLDs were positively correlated with ratings from the video clips (PLD0°: $r = 0.59$, PLD45°: $r = 0.72$), and that the two PLD angles were positively correlated ($r = 0.68$). Based on these results and the arguments presented above, both types of PLDs were used as stimuli.

Once all display types (video clip, PLD0° and PLD45°) were created for each series (one series = one back and forth), one of three series for each walker and each condition (sick and healthy) was selected. To select the series with the most natural walk (i.e., avoid the first series) and when the walker had spent longest time on the task (i.e., avoid the last series), the series were selected in the following priority: 3rd series, 2nd series, 4th series. Hence, if the video clip and/or the PLD for the third series was unusable (e.g. because of twitching joints), the ones from the second series were used. Due to technical problems with the recording of the motion data, one PLD45° and three PLD0°s were missing in the final sample. Consequently, 34 video clips, 33 PLD45°s, and 31 PLD0°s were used (see Fig. 2). Detailed information about the selection of series can be found in Supplementary Table S1.

2.3. Sickness detection

In two studies, the video clips and PLDs were shown to separate groups of participants. Both studies were advertised on student campuses in the Stockholm area and two online systems (the Psychology KI testing recruitment system and studentkaninen.se). Participants had to be at least 18 years old and speak Swedish or English fluently. Based on our previous study on sickness detection, with strong power for detecting main effects with 62 raters (Axelsson et al., 2018), we aimed to include 100 participants in each study (giving good power to also



Fig. 2. Examples of the three display types: video clip, PLD shown from the front (PLD0°), and PLD shown with a 45-degree angle (PLD45°).

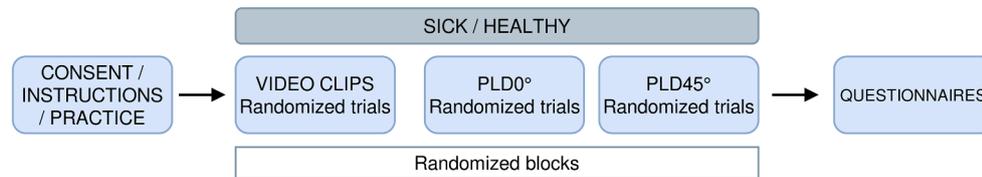
analyze predictors of sickness detection). Additional subjects were included to cover possible exclusions, resulting in 106 raters providing data in each study. A post-hoc power analysis shows that this sample size gives strong (98%) power to detect small-to-midsized effect sizes ($f = 0.20$).

Participants rated the walker as sick or healthy (study 1, see below) or rated the walker's health, tiredness, and, sadness on visual analogue scales (study 2, see below). Ratings of tiredness and sadness were included to replicate findings from a previous study (Sundelin et al., 2015), and results are included in Supplementary Table S2. A fixation time of three seconds preceded each stimulus. Before starting the task, raters gave informed consent, read the instructions, and conducted three practice trials (one for each display type) on stimuli not shown during the task. Participants were informed about the rating procedure and that the video context was from a hospital setting. They were instructed to not focus on the clothes of the walkers. In addition, they were instructed to answer quickly and to not think too much about their answer. Participants were naïve to the design and purpose of the study, and debriefed after participation. The tasks were presented with the software OpenSesame (Mathôt et al., 2012) in Swedish or in English, and participants had a response time limit of five seconds for each stimulus. Following the task, they filled out questionnaires outside the scope of the current paper. The design of the tasks of each study is illustrated in Fig. 3.

Study 1: sick/healthy task. In study 1, 106 raters (70 women, average age: 30.3 ± 8.9 years) decided whether the walker in each trial was "Sick" or "Healthy". The position of the words (Sick/Healthy) was counterbalanced between raters. Stimuli of each display type (video clip, PLD0°, and PLD45°) appeared in a randomized order (with the condition that the same walker was not shown twice in a row) in each block (Fig. 1A), resulting in three blocks, which order was randomized. Given that raters watched each stimulus once, there were 98 trials. In total, the study lasted for approximately 40 min. Raters were compensated with one movie ticket.

Study 2: ratings of health on a visual analogue scale. In study 2, 106 raters (57 women, average age: 28.6 ± 8.1 years) assessed each stimulus on three different visual analogue scales. The scales measured apparent health ("How was the person's health?" from "very good" to "very bad"), tiredness ("How tired was the person?" from "not at all tired" to "very tired") and sadness ("How sad was the person?" from "not at all sad" to "very sad"), and the position of the endpoints (e.g., "very good" and "very bad") were counterbalanced between raters. Each rating was saved as a value between 0 and 100 (higher values reflecting worse outcomes). The ratings (health, tiredness, and sadness) were separated into three main blocks with a break of two minutes between each block to avoid fatigue. Each main block consisted of three sub-blocks, one for each display type (video clip, PLD0°, and PLD45°)

A. Study 1



B. Study 2

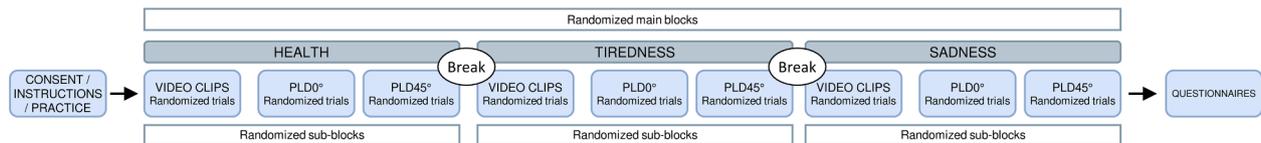


Fig. 3. Design of study 1 (A) and study 2 (B). Study 1 and study 2 lasted for approximately 40 min and 90 min, respectively. The main blocks in study 2 were separated with breaks of two minutes to avoid fatigue. Trials were randomized with the condition that the same walker was not shown twice in a row.

(Fig. 1B). As in study 1, the orders of the main blocks and the sub-blocks were randomized, while the order of the stimuli was randomized with the condition that the same walker was not shown twice in a row. Each type of rating was done separately for each stimulus, resulting in each stimulus being rated on three occasions (i.e., 294 trials). The study took approximately 90 min and raters were compensated with two movie tickets.

2.4. Predictors

Biological motion parameters (i.e., stride time (msec), stride width (m), head angle ($^{\circ}$), knee flexion angle ($^{\circ}$), arm extension angle ($^{\circ}$), and stride length (m)) were obtained from the 3-D coordinates with the Kinect® camera, from the same series as shown in the displays. As in Lasselin et al., 2020b, we measured the intensity of sickness responses using the measurement closest to the walking task: sickness symptoms assessed with the Sickness Questionnaire (Andreasson et al., 2016) 1.5 h post-injection, interleukin-6 concentration (area under the curve) from 1 h to 2 h after the injection, back pain (visual analogue scale) 2 h post-injection, and body temperature 2 h post-injection. One walker missed measurements of interleukin-6 concentration for both conditions due to difficulties in taking blood.

2.5. Statistical analyses

Statistical analyses were conducted in R, version 4.2.0 (R Core Team, 2017). The analysis plan was preregistered on OSF (<https://osf.io/tkdv2>) before conducting the analyses. The data set includes sensitive data for the walkers and thus cannot be openly shared according to GDPR. However, the data are available upon request (and ethical authorization) to julie.lasselin@ki.se. The focus of the current work was to investigate if sick individuals can be identified from biological motion, regardless of display type. Hence, all analyses were conducted separately for video clips, PLD0°s, and PLD45°s. All mixed models were conducted with the *lmer* function in the *lme4* R package (Bates et al., 2015), with the covariance structure unstructured. The statistical significance for linear regression models and mixed models was tested with a likelihood ratio test to compare full models to models without the variable of interest, using the *Anova* function from the *car* R package (Fox and Weisberg, 2019), with an alpha level set to 0.05. See the analysis plan (<https://osf.io/tkdv2>) for details of the statistical procedure.

Sickness detection and perception of health. For study 1, the proportion of stimuli with sick walkers that were correctly rated as sick and the proportion of stimuli with healthy walkers that were correctly

rated as healthy were calculated as sensitivity and specificity, respectively. Discriminability (d') and decision criterion (c) were calculated with the R package *Psycho* (Makowski, 2018). The discriminability reflects the ability to discriminate between sick and healthy walkers ($d' = [z(\text{hits}) - z(\text{false alarms})]$), with a higher d' indicating an increased ability. The decision criterion ($c = - [z(\text{hits}) + z(\text{false alarms})]/2$) indicates how liberal or conservative the raters were when rating the walkers as sick; a positive c corresponds to a conservative criterion with few walkers rated as sick and thus a low number of hits and false alarms, while a negative c corresponds to a liberal criterion with a high number of hits and false alarms. Thus, a criterion close to 0 indicates an unbiased criterion. Sensitivity, specificity, discriminability, and decision criterion were calculated separately for each rater and then averaged across raters. To determine the discrimination accuracy between sick and healthy, receiver operating characteristic (ROC) curve analyses were conducted with the R package *pROC* (Robin et al., 2011) for all stimuli and then separately for each walker. A ROC analysis provides a plot of sensitivity as a function of false alarms (1-specificity) with an area under the curve value where 1 indicates perfect detection and 0.5 complete randomness. All analyses were conducted separately for the display types.

In study 2, linear mixed models were used to determine how the condition of the walker (i.e., sick or healthy) affected apparent health. The models included random intercepts for each rater and each walker, and random slopes for walker condition by rater and by walker. Hence, the full models had the following structure: health rating \sim walker condition + (1 + walker condition | walker ID) + (1 + walker condition | rater ID). For these models, health ratings were inverted so that higher scores indicated better health. All analyses were conducted separately for the display types. Similar results were obtained when analyzing the data excluding outliers (see Supplementary Tables S3–S4).

Predictors of sickness detection and changes in apparent health.

The ROC scores for the walkers (i.e., the discrimination accuracy for each walker) were used as the dependent variable in linear regression models conducted to assess predictors for sickness detection in study 1. Firstly, we investigated which differences in sickness-associated biological motion between the sick and healthy condition that predicted sickness detection. Secondly, we investigated which changes in sickness responses (i.e., the change during sickness as compared to healthy condition) predicted sickness detection. All analyses were conducted separately for display types.

For study 2, the change in apparent health (Δ health) of the walker when sick compared to when healthy was calculated for each walker in each rater. Thus, a positive Δ health score indicated that a sick walker was rated as having worse health (=being sicker) compared to the same

walker when healthy. We then examined which differences in the sickness-associated biological motion parameters described above that predicted changes in apparent health. The models included random intercepts for each rater and each walker: $\Delta\text{health} \sim \Delta\text{stride time} + \Delta\text{stride width} + \Delta\text{head angle} + \Delta\text{knee flexion angle} + \Delta\text{arm extension angle} + \Delta\text{stride length} + (1 | \text{walker ID}) + (1 | \text{rater ID})$. All biological motion parameters (Δ -values) were scaled (i.e., z-transformed) prior to analysis. Similarly structured linear mixed model assessed which differences in sickness responses that predicted changes in apparent health: $\Delta\text{health} \sim \Delta\text{sickness symptoms} + \Delta\text{interleukin-6} + \Delta\text{pain} + \Delta\text{body temperature} + (1 | \text{walker ID}) + (1 | \text{rater ID})$. Multicollinearity was checked with the variance inflation factor (VIF) for all models assessing predictors (all VIFs < 2). All analyses were conducted separately for display types.

3. Results

3.1. Sickness detection and apparent health

The raters detected sick walkers as sick (sensitivity) and healthy walkers as healthy (specificity) better than chance (greater than 50%) for all display types, see Table 1. When considering the ROC curve values, the lower confidence interval value was higher than 0.5 for all display types, indicating that raters could detect sick walkers above chance level. Moreover, ROC curve analyses separately for each walker showed that raters could discriminate more than 50% of the walkers, regardless of display type. The d' values were between 0.54 and 0.94 depending on the display type. The decision criterions were close to 0, indicating that the raters were close to unbiased while classifying the walkers as sick or healthy.

In study 2, walkers were perceived by raters as having worse health when made sick experimentally than when healthy, from video clips ($B = -15.3$, $SE = 3.1$, $X^2 = 23.9$, $df = 1$, $p < .001$), from PLD0°s ($B = -9.3$, $SE = 2.7$, $X^2 = 11.5$, $df = 1$, $p < .001$), and from PLD45°s ($B = -12.4$, $SE = 3.2$, $X^2 = 14.9$, $df = 1$, $p < .001$) (Fig. 4).

3.2. Predictors for sickness detection and change in apparent health

Several biological motion parameters predicted identification of sick walkers in study 1 (Fig. 5A). For video clips, shorter step was the only parameter that predicted a better sickness detection. Sick walkers presented in PLD0°s were more correctly identified as sick if they had

Table 1
Identification of sick individuals in study 1.

	Video clip	PLD0°	PLD45°
Sensitivity ¹	59%	58%	56%
Specificity ²	74%	59%	63%
ROC area (95% CI) ³	0.67 (0.65–0.68)	0.59 (0.57–0.60)	0.60 (0.58–0.61)
Proportion of sick walkers identified as sick, % (n/total) ⁴	71% (12/17)	53% (8/15)	69% (11/16)
Discriminability, d'^5	0.94	0.48	0.54
Criterion, c^6	0.21	0.02	0.08

The table shows results for identification of sick individuals from video clips and PLDs. Video clips showed walkers with blurred faces, while PLDs consisted of one stride presented in a loop either facing the rater (PLD0°) or at a 45° angle (PLD45°). ¹proportion of stimuli with sick walkers correctly rated as sick. ²proportion of stimuli with healthy walkers correctly rated as healthy. ³detection rate (1 = perfect discrimination, 0.5 = random). ⁴proportion of the walkers with an area with the lower 95% CI range above 0.5. ⁵difference in the z-transformed probability of sick walkers correctly detected as sick (hits) and of healthy walkers rated as sick (false alarms), 4 raters had no false alarm in the video clips and 1 rater had no false alarm in the PLD45° and thus were not counted in the calculation. ⁶bias with a value closer to 0 indicating less bias. **Abbreviations:** PLD: Point-light display, ROC: receiver operating characteristics, CI: confidence intervals.

slower and more rigid steps, while shorter, slower, wider, and more rigid steps predicted a better sickness detection from PLD45°s. Differences in sickness responses (sickness symptoms, interleukin-6 concentration, pain, and body temperature) between the two conditions did not predict identification of sick walkers. The detailed results can be found in [Supplementary Tables S5–S6](#).

Fig. 5B shows the variables that predicted change in apparent health while rating sick walkers compared to the same walkers when healthy (study 2). LPS-induced slower, shorter, and more rigid steps predicted worse health ratings of sick walkers in the video clips. For PLD0°s, shorter and more rigid steps after the LPS injection compared to the saline injection predicted worse health ratings, while the same parameters along with LPS-induced slower walking speed and more head tilting downwards were predictors for health ratings for PLD45°s. LPS-induced increase in interleukin-6 concentrations predicted worse health ratings of sick walkers in the video clips, but no other sickness response parameter predicted change in apparent health for any of the display types. Detailed results can be found in [Supplementary Tables S7–S8](#).

4. Discussion

With two studies, we demonstrate that a transient activation of the immune system can cause detectable changes in gait patterns. In study 1, raters identified sick walkers in video clips and point-light displays (PLDs) better than chance. In study 2, sick walkers in video clips and PLDs were perceived as having worse health compared to the same walkers when healthy. These results extend our previous finding that sick walkers can be identified from video clips (Sundelin et al., 2015). The results also show that sickness can be detected solely from biological motion and posture (i.e., from PLDs). Furthermore, sick walkers were easier to identify and perceived as less healthy if they had a more rigid and slower walk when sick compared to when healthy, indicating that sickness-induced differences in several biological motion parameters might predict health perception.

For disease avoidance to be effective, there is a need for correct identification of sick individuals (Schaller and Park, 2011), and previous work shows that humans can use several sensory cues of sickness (Axelsson et al., 2018; Olsson et al., 2014; Sundelin et al., 2015). In the present studies, we show that identification of sick individuals can be based on very scarce information – PLDs only presenting one stride in a loop. Thus, this work adds to the existing literature on sickness detection by highlighting that brief biological motion can serve as a cue for sickness, possibly enabling humans to avoid infectious threats while keeping a distance (Thornton et al., 2014). It is likely that humans, when possible, use several cues to identify sick individuals, as multimodal perception increases the signal-to-noise ratio, especially when signals are weak (Regenbogen et al., 2017). For instance, one study used a combination of facial and odor cues and found that sick faces were rated as less likable when paired with sick body odors (Regenbogen et al., 2017). It would thus be valuable to determine the dynamic combination of biological motion with other sickness cues on sickness detection in future studies.

In previous studies, detection of walker traits were often favored when the PLD was moving towards the observer (Alaerts et al., 2011; Troje et al., 2005), but our previous study indicated that some biological motion parameters relevant for sickness detection might have been favored by a side view (e.g., head tilting more downwards) (Lasselien et al., 2020b). We found that raters were able to identify walkers in PLDs both when presented facing the rater and when presented slightly from the side (45° angle). In study 1, LPS-induced slower walk with more rigid steps predicted sickness detection from both types of PLDs, while smaller and wider steps only predicted detection from PLDs viewed from the side. In study 2, LPS-induced smaller and more rigid steps predicted changes in apparent health from both types of PLDs, while slower steps and more head tilting forward predicted detection from PLDs viewed

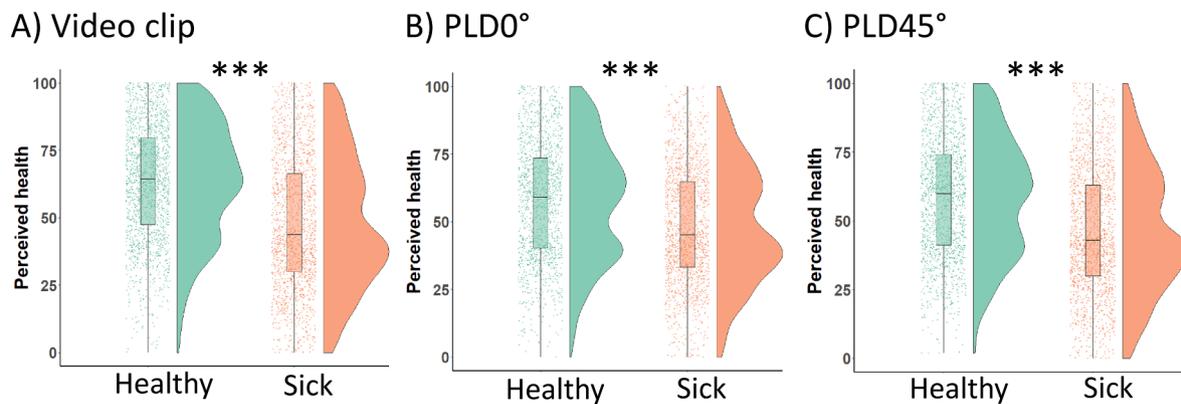


Fig. 4. Apparent health of walkers. Raters scored each walker's health on a visual analogue scale ranging from "very bad" to "very good" (a high score indicating good health) from video clips (A), PLD0°s (B), and PLD45°s (C). The data are visualized with raincloud plots (Allen et al., 2019). *** $p < .001$. Abbreviations: PLD: Point-light display.

from the side. Hence, our results indicate that different information provided from the two PLDs was used for sickness detection, and that sickness detection from biological motion might be more efficient when all the changes induced by immune activation can be perceived. Based on our findings, we propose that future investigations could pursue biological motion as a possible diagnosis tool, where gait and posture profiles combined with other modalities, such as facial cues, would be used to program artificial intelligence devices to estimate health status.

The difference in sickness responses (sickness symptoms, interleukin-6 concentration, pain, and body temperature) in sick walkers compared to the same walkers when healthy did not predict sickness detection or changes in apparent health while rating PLDs. We expected these parameters to serve as predictors considering that more sickness symptoms, higher interleukin-6 concentration, and lower body temperature did predict changes in gait patterns in the same sick walkers (Lasselin et al., 2020b). We did find, nonetheless, that LPS-induced increase in the pro-inflammatory cytokine IL-6 predicted worse rated health scores for the sick walkers in the video clips. It is possible that the increase in IL-6 affected additional cues that could be perceived only in this display type. For instance, acute inflammation affects skin color (Henderson et al., 2017), and the visible skin (e.g., on arms) could therefore serve as an additional cue in the video clips.

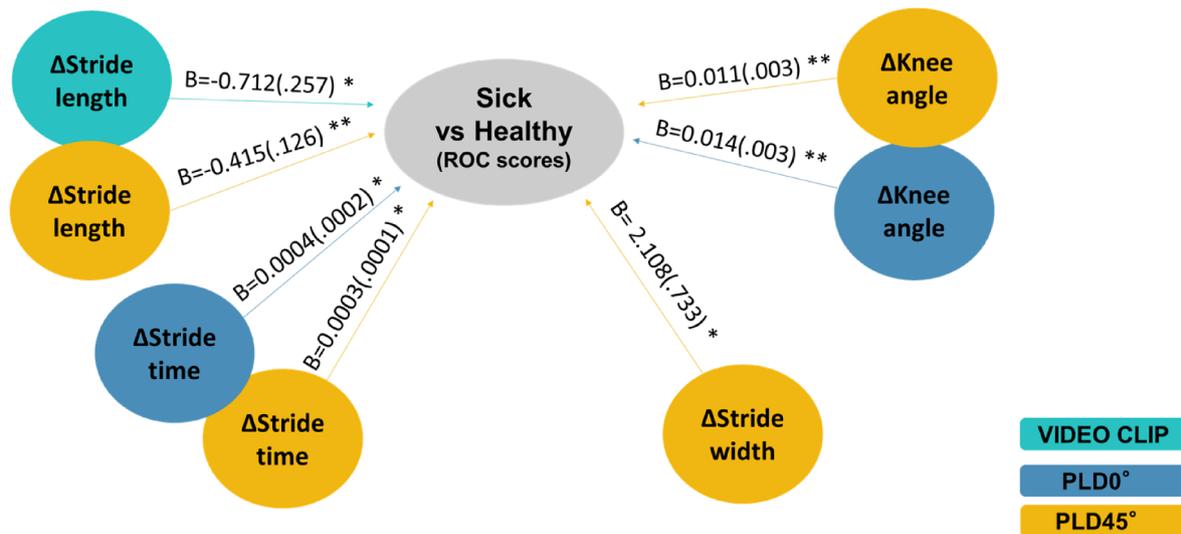
Several studies across taxa have demonstrated avoidance of sick individuals (Stockmaier et al., 2021). In humans, there are no studies on avoidance *per se*, but decreased likability of sick subjects compared to the same subjects when healthy has been argued to be a proxy for avoidance (Regenbogen et al., 2017; Sarolidou et al., 2020). Additionally, some studies indicate that the immune system can be triggered by visual sickness cues. For instance, pictures of individuals with clear sickness signs potentiated immune responses *in vitro* (Schaller et al., 2010), and videos with disease-associated content increased the level of antibodies in the saliva of the observer (Keller et al., 2022). Hence, humans seem to be able to respond proactively to infectious threats, both by avoiding contamination and by preparing the body for a potential infection. Importantly, avoidance might not always follow sickness detection. In some cases, animals might benefit from the opposite, i.e., approaching a sick individual (e.g., to take care of a kin) (Kessler et al., 2017). A future direction will be to investigate the contextual factors that shape approach-avoidance behaviors towards sick peers in humans.

One limitation of the current study is that the quality of the PLDs varied due to limitations of the recording device (Kinect®). However, results from the pilot (see methods, "Processing of stimuli – Point-light displays") indicated that ratings of video clips and corresponding PLDs were moderately to strongly correlated ($r = 0.59–0.72$), indicating that the quality of the PLDs was sufficient. Our previous study also shows that biological motion parameters are highly reproducible across trials

(Lasselin et al., 2020b), attesting to the reliability of the Kinect® to provide PLDs without the need of sensors on the body. Another limitation is that, because we wanted to assess how LPS-induced differences in biological motion parameters and sickness responses predicted sickness detection and change in apparent health, we used delta values, inducing additional error variance. The sick walkers were injected with a relatively high dose of LPS (2.0 ng/kg of body weight) and were recorded during the peak of sickness symptoms (Lasselin et al., 2017). More studies are thus needed to verify that sick individuals with less acute symptoms can be identified solely from biological motion and posture (i.e., from PLDs), and if such detection even occurs before other symptoms develop. Studies using stimuli from "naturally" sick individuals would provide important insight on generalizability of our findings. Recent studies show that humans can detect natural illness from faces (Leung et al., 2023) and odors (Tognetti et al., 2023), but this has yet to be investigated for gait patterns. Additionally, it is not clear whether sickness-induced gait alterations can be detected across cultures, as it was the case for faces (Arshamian et al., 2021). Given the design of the tasks, it is not clear how results from the current studies translate to a more ecologically valid setting. For instance, a future direction would be to investigate if sick individuals can be identified from a crowd in a natural habitat.

One important consideration is that it is possible that the detectable inflammation-induced changes in gait patterns are not specific to sickness: it remains unknown if raters would characterize the walkers as sick without the contextual underpinning of health perception. Instead, the raters might have detected unspecified deviations in the biological motion parameters that, here, were assigned to sickness. Notably, chronic conditions such as depression and chronic fatigue syndrome are characterized by a similar gait profile as in the present study (Michalak et al., 2009; Paul et al., 2008). It is possible that a behavioral defense system towards disease has developed according to a "smoke detector principle", enabling the system to detect unspecific cues and thereby avoidance of possible infectious threats (Schaller and Park, 2011). In study 2, sick walkers were rated as more tired and sadder compared to the same walkers when healthy (see Supplementary Table 2). These findings replicate previous studies showing that sick individuals are perceived as less happy and more tired (Sarolidou et al., 2019; Sundelin et al., 2015). Importantly, tiredness and sadness are not attributes irrelevant for sickness. For instance, sickness is characterized by negative mood (Harrison et al., 2009) and sleepiness (Lasselin et al., 2020a). Yet, sleep deprived individuals look sadder, lonelier, and are less socially desirable (Ben Simon and Walker, 2018; Sundelin et al., 2017, 2013). It is thus possible that sick walkers are detected as sick, and are more likely to be avoided, *because* they look tired and sad. However, one could also argue that sad and sleepy individuals are detected as such *because* they look sick. Future work will need to disentangle how different aspects of

A. Identification of sick individuals (study 1)



B. Change in apparent health (study 2)

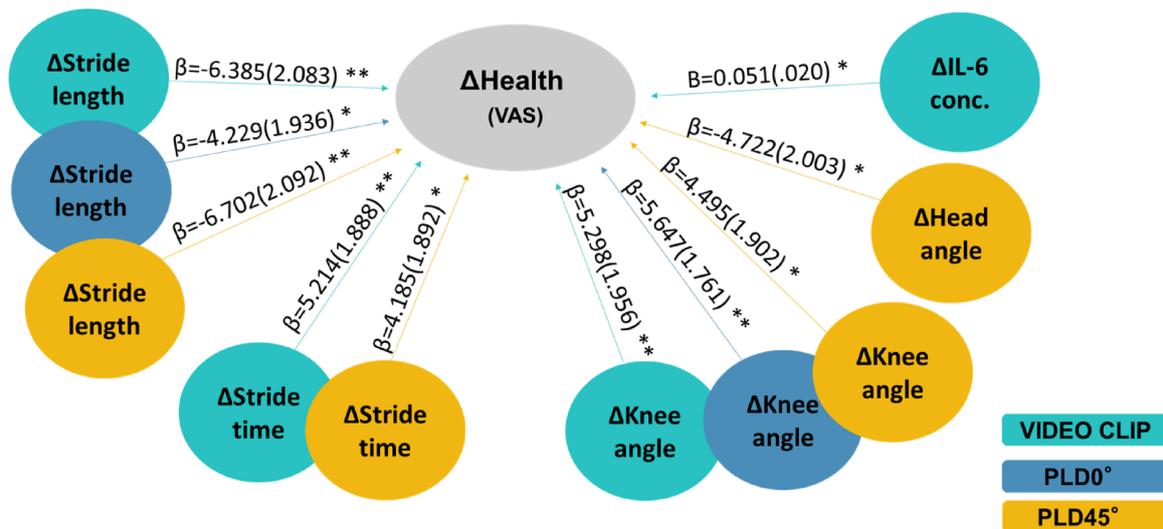


Fig. 5. Predictors for identification of sick individuals and change in apparent health of sick walkers compared to the same walkers when healthy. The predictors are displayed separately for video clips (turquoise), PLD0°s (blue), and PLD45°s (orange). Results for the other parameters can be found in [Supplementary Tables S5–S8](#). (A) The figure shows the parameters that predicted identification of sick individuals. (B) The figure shows the parameters that predicted change in apparent health of sick walkers compared to the same walkers when healthy. Delta values for biological motion parameters were scaled (i.e., z-transformed) prior to analysis. Results from all linear regression models and linear mixed models are presented as β/B (standard error of mean). * $p < .05$ ** $p < .01$. *Abbreviations:* PLD: Point-light display, ROC: receiver operating characteristics, VAS: visual analogue scale, IL-6 conc: interleukin-6 concentration, Δ Health: walker rating when sick – walker rating when healthy. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

ill-health relates to detection of sickness.

In conclusion, we demonstrate that raters were able to identify sick individuals by observing brief video clips and PLDs of walking individuals injected with either LPS or saline. This was confirmed in two separated studies where naïve raters either classified walkers as sick or healthy, or rated the health of the walkers. Furthermore, sickness detection and changes in apparent health while sick were both predicted by a LPS-induced slower and more rigid walk. This ability to identify sick individuals at a distance might facilitate avoidance of contagion.

Funding

The studies were supported by a grant from the KI research foundation (2018-02347 to J.L.). The study from where the stimuli were

obtained was supported by the Swedish Research Council (421-2012-1125 to M.J.O), the Swedish Foundation for Humanities and Social Sciences (P12-1017 to M.J.O), and Stockholm Stress Center, a FORTE (Swedish Council for Working life and Social Research) Center of Excellence (2009-1758).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

We are grateful for a number of people involved in the previous study from where the video clips and point-light displays were obtained: PhD MD S. Paues (Danderyd hospital, Karolinska Institutet, Sweden) who collected data together with J.L.; PhD MD A. Soop, PhD MD H. Wallén and PhD MD L. Hällström (Danderyd hospital, Karolinska Institutet, Sweden) who helped with the design and the medical procedures; as well as L. Gabrielsson and I. Hellström who helped with the data collection.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.bbi.2023.07.020>.

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