Effect on Postural Sway of the Invasion to Preferable Interpersonal Distance

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Abstract. This paper proposed a methodology which allows the detection of characteristic postural sways which relate to the invasion to preferred interpersonal distance. The result of empirical study revealed that, at least in most cases under the condition of standing posture, the characteristic change points of postures which are caused by bodily sway can be identified based on the analysis of body pressure distribution using the biomechanical reference models. This methodology based on non-verbal behavior is also expected to be helpful to analyze problematic phenomena of the invasion to personal space of individuals who have the difficulties of linguistic behavior.

Keywords: Interpersonal distance · Personal space · Methodology · Non-verbal behavior · Body pressure distribution

1 Introduction

The personal space concept is a useful tool to investigate human spatial behavior, and still well established especially in the literature of environmental psychology [3] and related areas. Various attempts are made to broaden the application of personal space. With more than thousand studies reported on personal space, however, many aspects of its details including the relationship with physiological behaviors, are still not clear.

1.1 Intrusion to Preferred Interpersonal Distance

It is well known that unwanted intrusion into personal space leads to psychologically discomfort and then results in a physically explicit behavior such as an unpleasant facial expression and a withdrawal tendency [13]. The question is what happens to individual prior to explicitly expressing unpleasantness.

Preferred, Explicitly Uncomfortable, Intolerable Interpersonal Distances. The present study distinguished the following three different interpersonal distances:

(A) minimum interpersonal distance that individual feels preferable and comfortable,
(B) interpersonal distance that individual begins feeling discomfort consciously and explicitly,

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(C) interpersonal distance that individual begins demanding its withdrawal if other approaches closer (ref. *flight distance* [6]).

Between three characteristic interpersonal distances above, two different types of boundary zones can be defined: (1) the boundary zone AB where individual feels some strange with the distance to the other but doesn't feel discomfort explicitly and (2) the boundary zone BC where individual feels discomfort explicitly but doesn't yet demand withdrawal. Our study focuses on the area where the preferred interpersonal distance is invaded, but individual doesn't yet demand its withdrawal (i.e. between A and C). Especially, we shed light on the boundary zone AB, an important area of maintaining the comfortability.

Non-verbal Method for Capturing Invasion to Preferred Interpersonal Distance. The most commonly used methods to measure personal space are based on stop-distance methods and naturalistic observation methods, which had been widely used and evaluated as feasible techniques for experimental and naturalistic filed studies, respectively [5]. In the use of the stop distance procedure, the subjects are instructed in which an experimenter initially stands two meters from the subject and then slowly walks toward the subject until the subject becomes uncomfortable and halts the experimenter's approach by saying stop. This method is useful to estimate the second category of interpersonal distance (explicitly uncomfortable) and to analyze phenomena in the boundary zone BC. Naturalistic observation methods can be employed to estimate the third category of interpersonal distance (intolerable) which allow the detection of the timing of withdrawal. On the other hand, as for the boundary zone AB in which individual doesn't begin feeling unpleasant explicitly and consciously, it is difficult to analyze spatial behavior by employing naturalistic observation methods which require an observable behavior or the stop-distance method which demands conscious verbal behavior. A non-verbal methodology is expected as a useful approach for investigating phenomena which occur especially in the boundary zone AB.

Objectives. The purpose of our study is to propose a methodology which allows the detection of phenomena which relates to the invasion to preferred personal space by employing a non-verbal method. Especially, we will shed light on phenomena which occurs in the boundary zone AB where individual feels some strange with the distance to the other but isn't aware of feeling discomfort consciously and explicitly.

This basic research is also expected to develop interesting potential applications. In particular, this methodology based on non-verbal behavior will be helpful for us to analyze undiscovered phenomena which relate to the invasion to personal space of person with difficulties of linguistic behavior, or of older elderlies. It also provides a useful basis for developing a technology that improves proxemic behavior of mobile social assistive robots, one of the important design aspect of mobile robots.

1.2 Our Approach

Postural Sway and Body Pressure Distribution at Foot and Buttock. In order to analyze phenomena in the boundary zone AB and BC, we focused on postural sway.

Postural sway was captured by applying body pressure distribution at feet (while standing upright) and buttocks (while sitting) (Fig. 1). By using a pressure sensor array, the body pressure distribution system tracks the center of pressure (CoP) and measures the pressure distribution between human body and support surfaces such as seats and insoles of shoes. Human bodily moves of surface level such as foot and buttock can be analyzed based on the change of pattern of body pressure distribution.

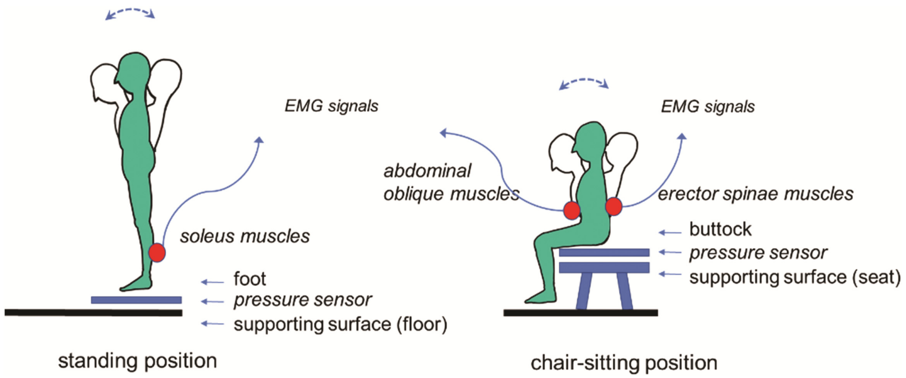

Fig. 1. Sensing postural sway (body pressure distribution and EMG signals)

Pressure distribution technology had been applied to various domains including a posture analysis during exercise and risk evaluation of pressure ulcers based on stress distribution in the gluteus muscles and enveloping fat in the buttocks during sitting for prolong time [2]. The challenge of the present study is to identify dynamic phenomena of very small bodily moves that occur and disappear in a moment.

EMG Signals from the Muscles that Maintain the Posture. Posture maintenance and control are fully dynamic process. The upright or sitting body is an inherently unstable system. In order to capture the electrical signals corresponding to muscle movements of the subject during a postural sway, Electromyography (EMG) was employed. EMG measures electrical activity in response to a nerve's stimulation of the muscle.

We focused on lower-limb muscles (soleus muscle) in a standing position, and back muscles (erector spinae muscle) and abdominal muscles (external abdominal oblique muscle) in a chair-sitting position (Fig. 1). These muscles were selected because they perform a range of functions which contribute the posture maintenance of standing or chair-sitting positions. For example in human standing, as gravity acts on the body to topple the person forwards, the whole body center of mass is typically maintained at a short distance in front of the ankle joints. Two muscles in the back of lower-limb, soleus and gastrocnemius, actively oppose the toppling effect of gravity [9].

Focusing on Standing and Chair-sitting Positions. By taking account into potential applications to situations of social assistance such as a care services for elderlies, we focused on both standing position and chair-sitting position.

Distinction of Different Combinations of Bodily Orientation. Because size and shape of interpersonal distance that individual permits has anisotropy [3, 7], the combinations of bodily orientation and approach angles were controlled and distinguished. Interpersonal distance was measured with the "center-center" model [8] which employs the distance between the vertexes of a participant and an approacher. Figure 2 describes the measurement of interpersonal distance based on the center-center model and the relationship between combinations of bodily orientations and approach angles.

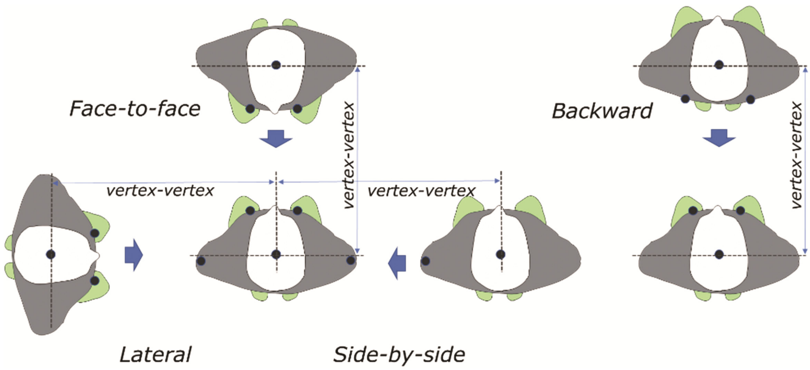

Fig. 2. Measurement of interpersonal distance in each combination of bodily orientation.

1.3 Our Hypotheses

The following hypotheses have been established prior to the present study.

1. When the other intrudes into individual preferred interpersonal distance, individual feels discomfort to current interpersonal distance, and causes a characteristic postural sway other than a verbal report and/or explicit physical behaviors such as an escape or unpleasant facial expression.
2. Postural sways above, verbalization of asking to stop approaching in the use of stop-distance method, and explicit physical behaviors such as an escape can occur at the different timings. Especially, postural sways possibly occur prior to the others.
3. The occurrence of postural sway above can be captured as a characteristic change pattern of CoP (center of pressure) and of body pressure distribution.
4. The occurrence of postural sway above can be captured as a characteristic change of muscular activities of postural maintenance.

2 Empirical Study I

The study I investigated how individual of chair-sitting position causes a postural sway when his or her preferred interpersonal distance is intruded. Body pressure mapping was employed. The experimental design of the study I is shown in Table 1. Under the condition of chair-sitting position, mainly hypotheses 1 and 3 were examined.

Table 1. The experimental design of the study I

Factor		Level	
Within subjects	Combination of posture	2	sitting(*)-sitting, sitting(*)-standing
	Combination of bodily orientations	4	face-to-face, backward from front, lateral direction(**), side-by-side (**)

Note (*): Posture of the evaluator (participant) indicated with (*).
Note (**): The participants were approached from a lateral of dominant hand.

2.1 Method

Participants. Eight healthy university students (3 males, 5 females, age range: 21–23 years) participated. The participants were recruited individually and were informed that the study dealt with spatial preferences. They gave their informed consent before participation in the study.

Setting. The data collection was carried out during daytime, in an empty and quiet class room (6.3 m × 5.5 m with a ceiling height of 3.0 m) of a university located in Tokyo metropolitan area. The brightness was appropriately maintained with an indoor lighting instead of natural light from outside. It took approximately one hour per participant.

Measurements and Experimental Arrangement
Interpersonal Distance. The inter-personal distance between vertexes of a participant and of an approacher was measured by using a laser range finder (BOSCH GLM7000), with the "center-center" model which is described in previous section.

Body Pressure Distribution. Pressure mapping technology was used to visualize the distribution of contact pressure between human body and a supporting surface of a seat. In study I, each participant was seated in a sheet of fabric on a chair. A sensor sheet of the body pressure recording system (NITTA BIG-MAT, 44 × 48 cm) was interposed between them. The sheet surface was positioned parallel to the ground. Pressure data were originally sampled at 80 Hz, digitalized at 8 bits, then stored by the pressure recording system (NITTA BPMS).

Procedure. According to the experimental design of study I, eight data (2 × 4, see Table 1) under different experimental conditions were obtained per each participant. In each condition, according to the stop-distance procedure, an assistant experimenter initially stood 2.5 m from the participant and then approached the participant, in small steps, at a constant slow velocity (approx. 20 cm/s), one step per two seconds, until the participant began to feel discomfort about the closeness. By saying stop, the assistant experimenter's approach halted. In order to minimize a measurement error, the participant was allowed to make fine re-adjustment of their positions. The distance remaining between the vertexes of the participant and the assistant experimenter was measured. During each session of data collection, a continuous measurement was made from 10 s before the beginning of approach and continued until 10 s after the halt of approach, which lasted for approximately one minute. Each dyad of a participant and an assistant experimenter was not acquaintances. Data collection was performed in November and December 2016.

2.2 Data Analysis

Data collected from eight participants under eight different experimental conditions were analyzed. Each data consisted of a set of (a) interpersonal distance according to the stop-distance method, and (b) pressure distribution between a participant's buttock and a supporting surface of a chair. Pressure distribution data were stored by the recording system for the analysis of pressure mapping including CoP tracking.

2.3 Results

Mean of all the interpersonal distances obtained from all the conditions is 77.05 cm (SD = 24.73). The observed data ranged between 28.0 (sitting-standing, lateral) and 158.0 (sitting-sitting, face to-face). Body pressure mapping system visualized the pressure distribution at a participant's buttocks. Figure 3 shows examples of body pressure mapping under the condition of face-to-face (left) and side-by-side (right), which were captured at the different timings: when a participant said "stop approaching" (namely, *ts*), ts-0.3, and ts-4.0 s for face-to face (Fig. 3-a); ts, ts-4.0, ts-8.0 s for sitting-sitting (Fig. 3-b).

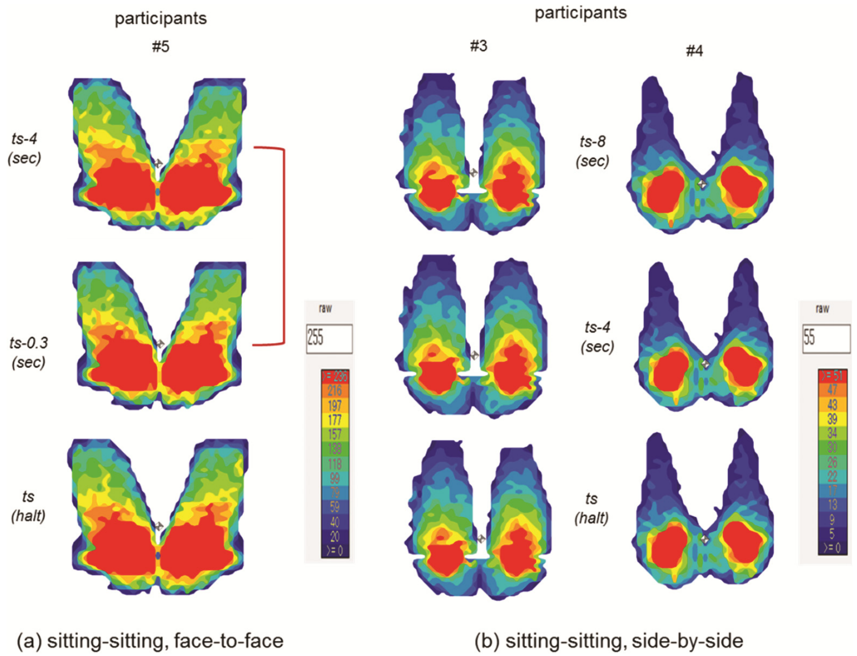

Fig. 3. Body pressure mapping at several timings (face-to-face, side-by-side).

The results of study I revealed that: (a) at least under a specific condition, significant changes of body pressure distribution were observed, for example, between the timings of ts-0.3 and ts-4 s (e.g. participant#5: {sitting-sitting, face-to-face}); (b) in some cases, the above significant changes were identified even before a participant said "stop approaching". In other cases, the above changes were not always observed based on pressure mappings (e.g. participant#3,4: {sitting-sitting, side-by-side}). No characteristic move pattern of CoP could be identified.

3 Empirical Study II

The study II investigated how the invasion of preferred interpersonal distance causes postural sway, based on body pressure distribution and EMG activity. The settings were enhanced to capture postural sway during sitting and standing upright. Hypotheses 1 to 4 were examined. The experimental design of the study II is shown in Table 2.

Table 2. The experimental design of the study II

Factor		Level	
Between subjects	Combination of gender	4	male(*)-male, male(*)-female, female(*)-male, female(*)-female
Within subjects	Combination of posture	3	sitting(*)-sitting, sitting(*)-standing, standing(*)-standing
	Combination of bodily orientations	2	face-to-face, side-by-side (the participants were approached from a lateral of dominant hand)

Note (*): The condition of a participant is described on the left of each pair.

3.1 Our Approach

Biomechanical Reference Model. We developed two biomechanical reference models of the foot and the buttock (Fig. 4) to analyze the relationship between body pressure mapping and a participant's bodily move based on biomechanical structure.

The foot has highly complex structure and functions. Based on MRI/CT scan images (e.g. [1]), subject-specific 3D finite element models of the foot were built to simulate the biomechanical behavior, for example, in order to predict the area characterized by excessive stresses on the plantar surface (e.g. [4]). A contact surface of the foot was first divided based on previous biomechanical studies [10], furthermore, its division was modified with an emphasis on the function of individual digit and plantar arch. Our reference model of the feet (ver. 1) consists of sixteen sections for both sides: big toe (T1); 2nd, 3rd, 4th and 5th toes (T2); forefoot medial (F1); forefoot intermediary (F2); forefoot lateral (F3); midfoot (M); heel (H); and plantar arch (A) (Fig. 4-a).

Some clinical researches recently employed subject-specific 3D finite element models of the buttock based on MRI/CT scan images to study the influence of material stiffness, soft tissue thicknesses and postures onto internal strains (e.g. [2]). The main

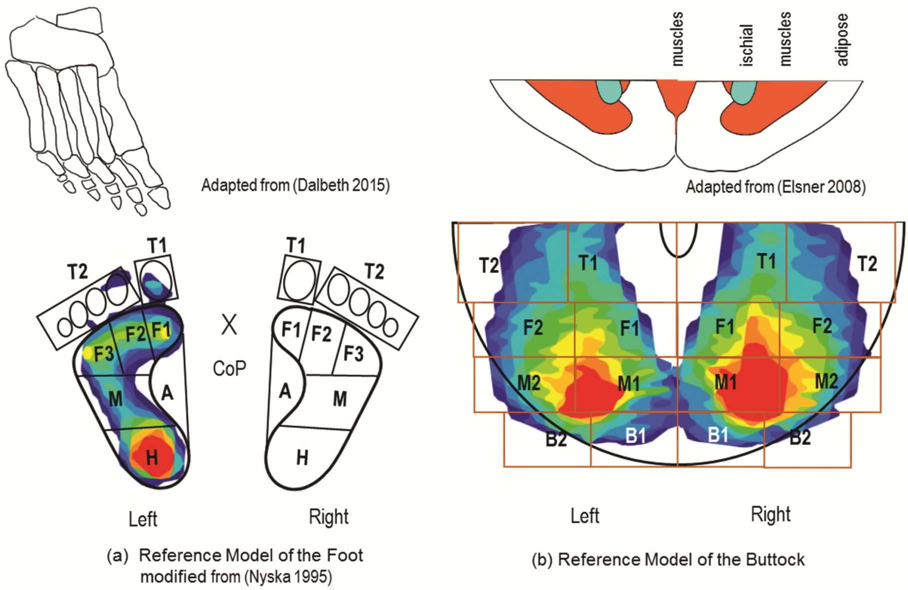

Fig. 4. Reference model and biomechanical sections of the foot and the buttock

structures constitute the surfaces of the skin, fat, and muscles and bone (ischial). Based on structural analysis, a contact surface of a buttock was divided into biomechanically useful sections, especially with an emphasis of the position of ischial. Our biomechanical reference model of the buttock (ver. 1) consists of sixteen sections (Fig. 4-b).

Body pressure distribution is calculated according to those biomechanical reference models. Those models can be adjusted to each subject by analogously transforming according to the size and shape of individual feet and buttock.

EMG Activities of the Muscles related to Posture Maintenance. EMG activity on both sides of lower-limb muscles (i.e. *soleus muscle*) in a standing position, and EMG activity on both sides of back muscles (i.e. *erector spinae muscle*) and abdominal muscles (i.e. *external abdominal oblique muscle*) in a chair-sitting position were recorded.

3.2 Method

Participants. Twelve healthy university students (5 males, 7 females, age range: 19–23 years) participated. They reported being usually moderately active. The participants were recruited individually and were informed that the study dealt with spatial preferences. They gave their informed consent before participation in the study.

Setting. The data collection was carried out during daytime, in an empty and quiet class room (6.3 m × 5.5 m with a ceiling height of 3.0 m) of a university located in Tokyo metropolitan area. The brightness was appropriately maintained with an indoor lighting instead of natural light from outside. It took approximately one hour per participant.

Measurements and Experimental Arrangement

1. *Interpersonal Distance.* The inter-personal distance between vertexes of each dyad of participants was measured with the "center-center" model which is described in previous section. The distance was measured by using a laser range finder (BOSCH GLM7000, measurement accuracy ±1.5 mm).
2. *Body Pressure Distribution.* Under the condition of standing position, a participant stood upright barefoot on a sheet on a floor. A sensor sheet of the body pressure recording system (NITTA BIG-MAT, 44 × 48 cm, spatial resolution 10 mm, sensor points 2112) was interposed between a participant's bare feet and supporting surface of a floor. The sheet surface was positioned parallel to the ground. Under the condition of chair-sitting position, the same experimental arrangement of the study I was applied. Body pressure data were sampled at 80 Hz, digitalized at 8 bits, then stored by the pressure recording system (NITTA BPMS) for subsequent analysis. Calibration of the pressure recording was made by the change of bodily positions.
3. *EMG Activity.* Pairs of disposable electrodes were attached over the bellies of the six different muscles. Electrodes over soleus muscles, erector spinae muscles and external abdominal oblique muscles were positioned 2.0 cm apart. The electrodes were connected to a biological amplifier (Guger Technologies g.USBamp). EMG signals were sampled at 1200 Hz, bandpass filtered (5–500 Hz), then stored for subsequent analysis, in addition to REF/GND. Due to a sufficient length of cables, participants' movement was not restricted by the recording apparatus.

Procedure. The data collection was performed by six different pairs of participants (A and B). They were not acquaintances. At first, one of participants (A) took a role of an evaluator and the other participant (B) took a role of an assistant experimenter (approacher). According to the experimental design, a set of six data (3 × 2, see Table 2) under different conditions were obtained per each participant. After all the data was obtained from a participant A, the participants exchanged their roles.

The stop-distance method was employed to measure interpersonal distances. At first, an assistant experimenter initially stood 2.5 m from an evaluator and then approached an evaluator, in small steps, at a constant slow velocity (approx. 20 cm/s), one step per two sec., until an evaluator began to feel discomfort about the closeness. By saying stop, an assistant experimenter's approach halted. In order to minimize a measurement error, an evaluator was allowed to make fine readjustment of their positions. The remaining distance between the vertexes of the evaluator and the approacher was measured. During each session of data collection, a continuous measurement was made from 10 s before the beginning of approach and continued until 10 s after the halt of approach, which lasted for approximately 1.0 min. The data were collected in January and February 2017.

3.3 Data Analysis

Data collected from twelve participants under six different experimental conditions were analyzed. Each data of participant's bodily movement consisted of a set of (a) interpersonal distance, and (b) body pressure captured between a participant's buttock and a chair or between his or her feet and a floor, and (c) EMG signals from the soleus muscles, and erector spinae muscles and external abdominal oblique muscles. Body pressure data were analyzed based on pressure distributions/mapping according to the reference models, CoP tracking, averaged, and temporal reporting.

3.4 Results

Mean of all the interpersonal distances obtained from all the conditions is 75.06 cm (SD = 20.51). The observed data ranged between 36.0 (female-female pair, sitting-standing, side-by-side) and 128.3 (female-male pair, standing-standing, face to-face). Statistical analysis such as ANOVA was performed, however, that is out of scope of the paper.

Figures 5 and 6 show the composite summary charts based on the synchronized data obtained from the participants #5 and #8, under the condition of {standing-standing, face-to-face}. Figure 7 shows the composite summary chart based on the synchronized data obtained from the participant #8, under the condition of {sitting-sitting, side-by-side}. Each chart consists of tracks of elapsed time, interpersonal distance, snapshots of pressure mapping of their feet or buttocks at the timing of characteristic change points, and EMG signals. Figures 5 and 6 include temporal reports of EMG obtained from both sides of soleus muscles, whereas Fig. 7 involves EMG obtained from both sides of erector spinae muscles and external abdominal oblique muscles.

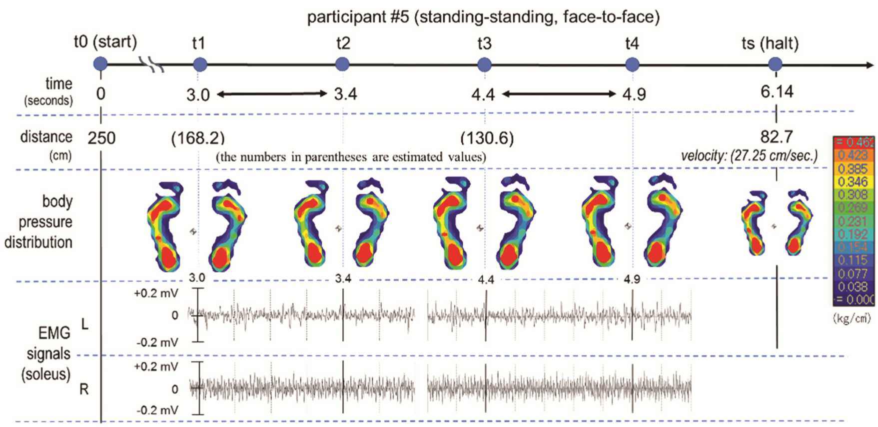

Fig. 5. Temporal change of distance, pressure mapping and EMG signals (participant #5)

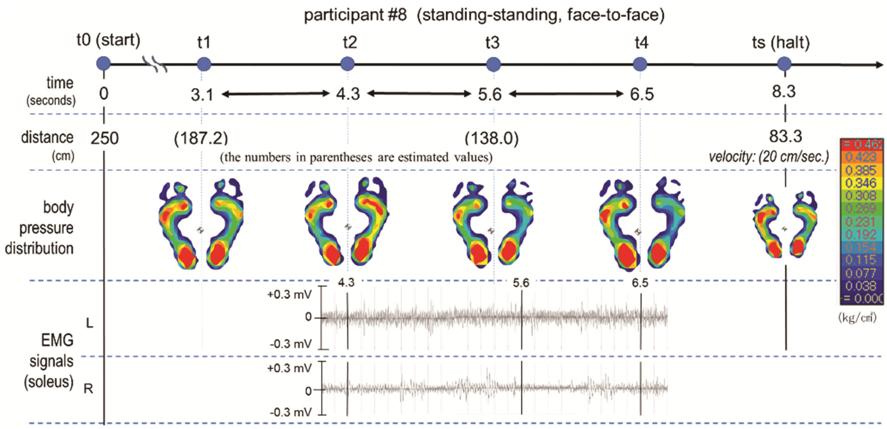

Fig. 6. Temporal change of distance, pressure mapping and EMG signals (participant #8)

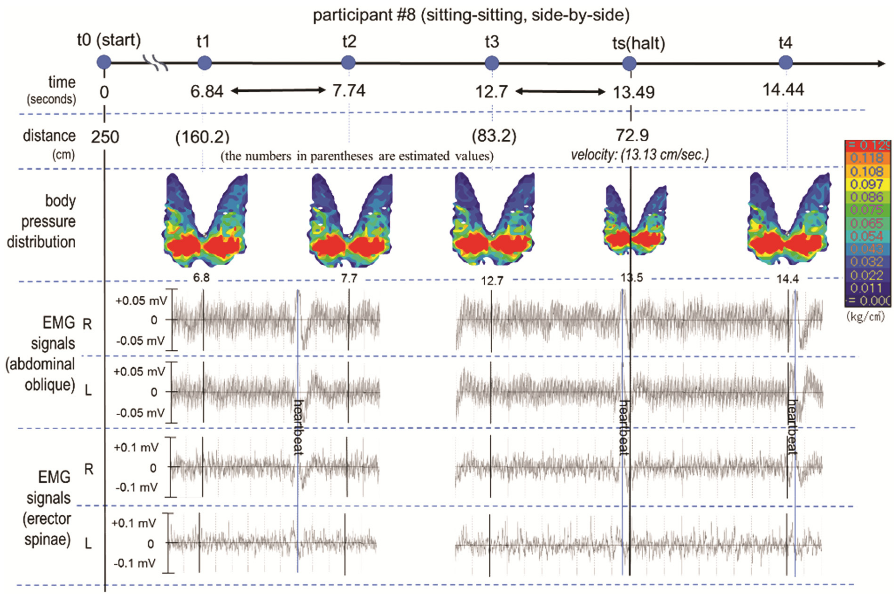

Fig. 7. Temporal change of distance, body pressure mapping and EMG signals (participant #8)

Analysis of Body Pressure Distribution. The characteristic change points of body pressure distribution were identified by detecting the points where the magnitude of the change or the change ratio of load ratio of each biomechanical section for the total load, had significantly increased or decreased during a short period.

Pressure Distribution of Feet While Standing. Figures 8 and 9 show temporal change of body pressure distribution of biomechanical sections of feet of the participants #5 and

#8, under the condition of {standing-standing, face-to-face}, by applying the reference model.

In the participant #5 (Figs. 5 and 8), four characteristic change points were identified other than an initial change point at the timing of the first step of approaching. During a period of 0.4 s between the point no.1 to no.2, the ratio for the total load increased at R-F1 (6.8%), L-H (4.3%), and R-H (3.2%), whereas it decreased at L-M (−6.6%), R-M (−4.0%) and R-F2 (−3.2%). Also, during a period of 0.5 s between the point no.3 to no. 4, the ratio for the total load increased at R-M (2.9%) and R-F2 (1.0%), whereas it decreased at L-H (−1.0%) and R-F1 (−1.6%).

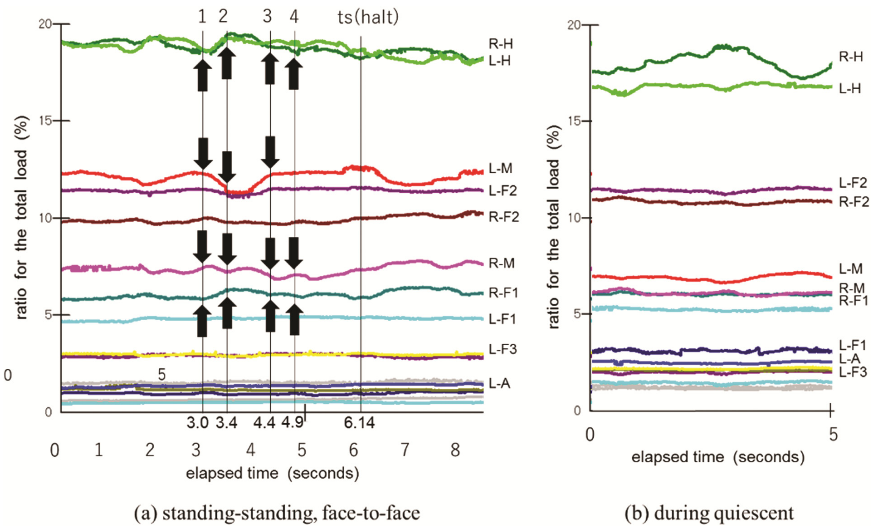

Fig. 8. Temporal change of body pressure distribution of feet (participant #5)

In the participant #8 (Figs. 6 and 9), four characteristic change points were identified other than an initial change point at the timing of the first step of approaching. During a period of 1.2 s between the point no.1 to no.2, the ratio for the total load increased at R-F1 (27.2%) and R-F2 (24.7%), whereas it decreased at L-M (−19.1%) and R-M (−12.8%). Also, during a period of 2.2 s between the point no.2 and no.4, the ratio for the total load increased at L-M (44.9%) and L-H (33.7%), whereas it decreased at R-F2 (−41.5%) and R-F1(−42.7%). In both participants, the above characteristic changes occurred in relatively short period whereas it smoothly changed in longer period while being quiescent (Figs. 8-b and 9-b).

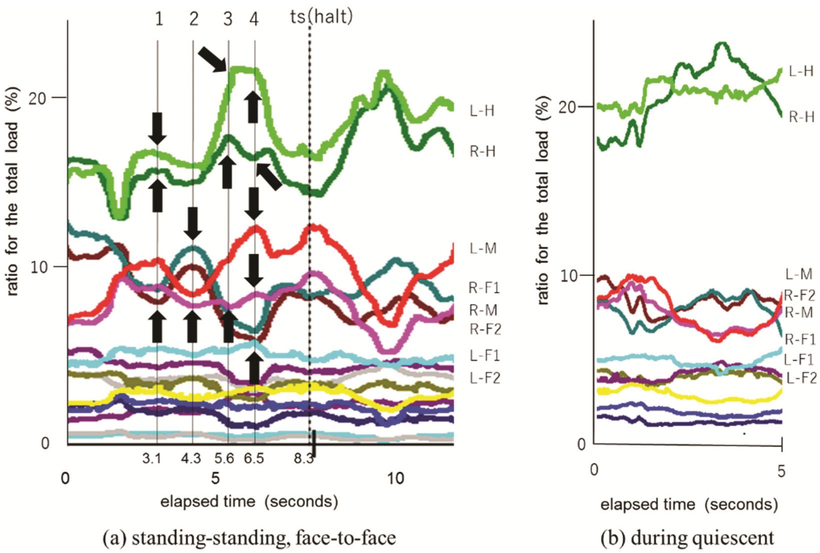

Fig. 9. Temporal change of body pressure distribution of feet (participant #8)

Pressure Dstribution of Buttocks While Sitting. Figure 10 shows temporal change of body pressure distribution of biomechanical sections of the buttocks of the participants #8, under the condition of {sitting-sitting, side-by-side}, by applying the reference model of the buttock. In the participant #8 (Figs. 7 and 10), four characteristic change points were identified other than an initial change point at the timing of the first step of approaching. During a period of 0.9 s between the point no.1 to no.2, the ratio for the total load increased at L-B1 (28.6%), L-M1 (3.2%), R-M2 (3.1%) and R-M1 (2.2%), whereas it decreased at L-F2 (−9.6%) and R-F2 (−7.5%). Also, during a period of 1.7 s between the point no.3 to no.4, the ratio for the total load increased at L-F2 (10.9%), R-F1 (6.3%) and R-F2 (3.3%), whereas it decreased at R-B2 (−14.3%), L-B2 (−15.4%), R-B1 (−10.5%) and R-M2 (−7.6%). On the other hand, it was almost flat while being quiescent (Fig. 10-b).

Analysis of EMG. Several identifiable characteristic patterns of EMG were found, for example, at soleus muscles, around t3 in Fig. 5, and around t3 in Fig. 6. They were very small changes in EMG activities in short period. Further analyses including frequency analysis are needed to elaborate the criteria of a characteristic pattern of EMG activity during postural sway. Examination of the other group of muscles can also be considered.

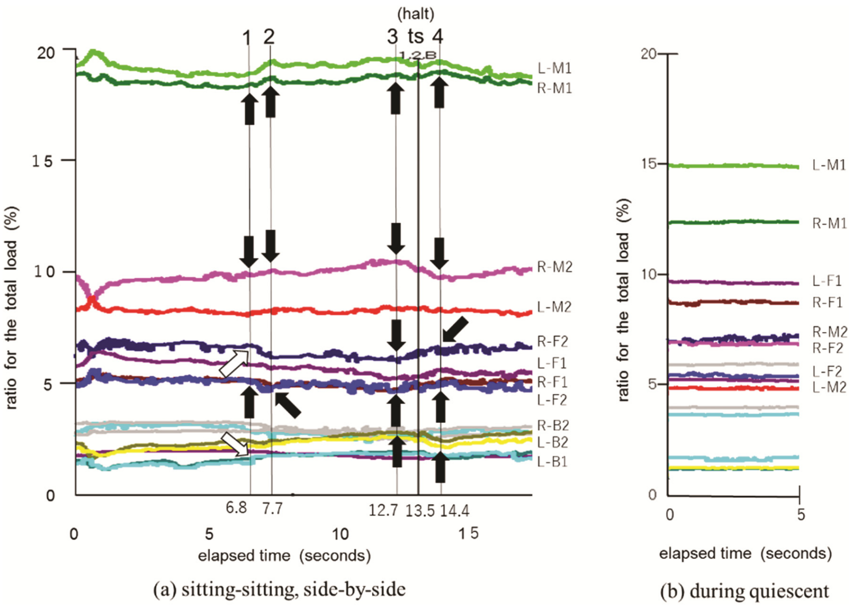

Fig. 10. Temporal change of body pressure distribution of buttocks (participant #8)

4 Discussion

The postural sways observed prior to the verbalization of "stop" involved a very small bodily move that occurred and disappeared in short period. In order to clarify the criteria of detecting a characteristic change of posture during approaching, further detailed analyses of the composite synchronized data based on multiple measurements including video and EMG will be effective. This integrated analysis approach will be also useful to investigate the detailed characteristics and mechanism of the occurrence of small characteristic postural sways during approaching and the emergence of a sort of mild affective state including feelings of discomfort, which are caused by the invasion to preferred interpersonal distance. Our future work involves a further characterization or segmentation of the boundary zone AB (between preferred and explicitly uncomfortable interpersonal distances) and a comparison with methods based on other non-verbal signs such as eyeblinks [11] and cardiovascular parameters including heart rate [12].

5 Concluding Remarks

This paper proposed a methodology which allows the detection of characteristic postural sways which relate to the invasion to preferred personal space. It employed body pressure distribution and EMG.

The results of our empirical study revealed that, at least in most cases under the condition of standing posture, the characteristic change points of postures which are caused by bodily sway can be identified based on the analysis of body pressure distribution using the biomechanical reference models of feet and buttocks. The characteristic change points of body pressure distribution were identified prior to and around the timing of verbalization of asking to stop approaching in the use of stop-distance method, and explicit physical behaviors such as an escape. The present study suggested body pressure distribution is a useful for identifying the effect on postural sway of the invasion to preferable interpersonal distance, however, it was very small bodily move that occurred and disappeared in short period. Further analyses will be needed to elaborate the criteria of detecting a characteristic change of posture during approaching and to verify the mechanism of the occurrence of small postural sway and the emergence of a sort of mild affective state including feeling uncomfortable, which are caused by the invasion to preferred interpersonal distance. This basic research is expected to provide a tool for identifying problematic phenomena of the invasion to personal space of individuals who have the difficulties of linguistic behavior.

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