Study of design factors for transfer-aid equipment based on caregivers’ feelings

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Abstract
To avoid back injuries, caregivers are advised to use transfer-aid equipment while transferring a patient from a bed to a wheelchair. Although the usage of such equipment has been recommended for several decades, it remains unpopular in several countries, including Japan. The current study investigates the feelings of caregivers regarding the usage of transfer-aid equipment, the cause of their feelings, and the measures that can be considered in order to increase the acceptance of transfer-aid equipment by the extensive caregiver community. The relations among the movements of users (caregivers and patients) and impressions of the caregivers regarding the equipment, while monitoring the usage of the equipment, were analyzed using Kansei engineering. The relations revealed six distinct feelings that are related to users’ movements while using the equipment.

Keywords: Kansei engineering, Transfer aid equipment, Nursing care, Delight map, Design factors

1. Introduction

Numerous wheelchair users have found it difficult to move from a bed to a wheelchair without any assistance. However, while moving a patient from bed to wheelchair, caregivers or nurses are required to carry a heavy physical burden by themselves (Nelson et al., 2003a). Back injuries caused by personal care or nursing are considered to be a particularly serious problem (Buckle, 1987) and are observed to be closely related to lifting the patients (Bell et al., 1979; Stobbe et al., 1988; Hoogendoorn et al., 1999; Retsas and Pinkahana, 2000). However, back injuries can be effectively prevented by the usage of transfer-aid equipment (Corlett and Corlett, 1992).

Various types of transfer-aid equipment have been developed (Nelson et al., 2003c; Krishnan and Pugazhenthii, 2014), and their appropriate use markedly reduces the injury risk (Zhuang et al., 2000; Nelson et al., 2003b; Baptiste et al., 2006; Schoenfisch et al., 2013; Andersen et al., 2014). The most popular type of transfer-aid device is a mechanical lift, which lifts the patient upward from the bed. Further, we observe that the mechanical lift can reduce the rate of musculoskeletal
injuries (Analee Yassi and Tait, 2002; Trinkoff et al., 2003; Collins et al., 2004). In some countries, the replacement of manual transfer using transfer-aid equipment is encouraged by the government or nursing federation of the country. The emplaced policies are often called the No Lift Policy or Minimum Lift Policy. For example, the Australian Nursing Federation has adopted a No Lift Policy since 1998, which has significantly reduced the proportion of nurses reporting the occurrence of back injuries (Engkvist, 2006; Martin et al., 2009). However, in other countries (including Japan), the penetration rates of transfer-aid equipment remain quite low and many caregivers continue to transfer patients unaided despite the heavy physical burden. Transfer-aid equipment may be rejected for various reasons that include the cost of introduction, area of installation, and psychological barrier against the use of mechanical equipment for transferring patients (Moody et al., 1996; Griffith and Stevens, 2004). For example, some caregivers hesitate to use the equipment for fear of injuring the patient or out of pity for patients being treated mechanically. The most important functionality of transfer-aid equipment is the prevention of back injuries to caregivers, and numerous studies have been conducted to prove this perspective. However, caregivers who have negative impressions regarding the usage of such equipment will remain unwilling to use the product. When designing transfer-aid equipment, the elimination of these psychological barriers should be considered to be a major goal. Nevertheless, the feelings of caregivers toward transfer-aid equipment and the cause of these feelings have been subjected to very few research studies.

This problem is rendered difficult by the various impressions of transfer aids evoked in caregivers. Even passively watching the use of transfer-aid equipment can trigger these impressions, which are based on the subjective perceptions of the caregivers. For example, motions and postures that caregivers hesitate to take may not depend on the physical burden incurred by these motions and postures. Therefore, the appearance of motion and posture alone can negatively affect caregivers’ impressions of transfer-aid equipment, even if such equipment helps to reduce the physical burden. Other impressions that are unrelated to physical burden include a perceived degradation of patient dignity, as mentioned above. When caregivers view different transfer-aid equipment, their impressions are strongly influenced by the different motions and postures adopted in the equipment use, which apply to both care-giver and patient. Therefore, the motions and postures caused by the use of transfer-aid equipment should be part of the product design. By relating the motions and postures of caregivers and patients to caregivers’ impressions of transfer-aid equipment, we can introduce a new evaluation criterion into the design of transfer-aid equipment that differs from evaluation based on the measured physical burden.

Many methods and techniques quantify the relationship between the quantifiable physical properties of a product and a user’s subjective impression of the product (Komazawa and Hayashi, 1976; Ishihara et al., 1995, 1996; Ishihara, 2001; Nagamachi, 2006; Demirtas et al., 2009; Huang et al., 2012; Chen et al., 2015; Chou, 2016), and have been adopted in many case studies of product design (Nagamachi, 1995; Schütte et al., 2004; Lokman, 2010; Levy, 2013). The development of an attractive product through relating the physical properties to user impressions is known as Kansei engineering. Adopting the Kansei engineering methodology, Yanagisawa et al. (2016) proposed the delight map for easy visualization and estimation of user responses that are proportional to design variables.

The present paper aims to understand caregivers’ feelings when viewing the motions and postures of caregivers and patients using transfer-aid equipment. The user impressions are analyzed on a delight map in Kansei engineering. The load-reduction functionality and other mechanical properties (appearance, size, weight) of the equipment are relatively easy to design; for example, the lighter the physical load, the better the equipment. The abovementioned relationship between impressions and perceived motions of caregivers and patients using the equipment is less tractable. For instance, physical properties of the product such as shape, color and size are easily handled by the Kansei engineering methodology, but motion extraction is less easily presented in this form. Whereas physical properties can be represented by scalar values or discrete variables, motion is a complex compendium of the movements of many human-body segments over time, and is usually represented by complex functions of time. Therefore, in this paper, we extract some features of the motion that can be represented by scalar values. These candidate features are applied as the physical properties of the product in Kansei engineering. Thereby, we derive the relationship between caregivers’ motions when using the transfer-aid equipment and their impressions of the equipment when seeing the motion. By synthesizing the motions of the caregivers and patients using the transfer-aid equipment as a function of the product and the caregivers’ impression of the equipment when observing this function, we can begin to understand whether caregivers will accept the equipment. This study provides a new perspective to the design of transfer-aid equipment that was previously based on physical burden alone.

This study was approved by the Human Subject Review Board of Tokyo Ariake University of Medical and Health Sciences.
2. Materials and methods

2.1. Modeling Framework and Overall Process

This paper is based on a common Kansei engineering approach Schütte et al. (2004) and the delight map methodology proposed by Yanagisawa et al. (2016).

The target domain is caregivers who usually decline the use of transfer-aid equipment for any reason. To understand why many caregivers reject the use of transfer-aid equipment despite official recommendations, this study focuses on the motions and postures of caregivers and patients using the equipment. The motions and postures were treated as a function of the product, as mentioned in Section 1. Next, a space of product properties was constructed by measuring the motions and postures of caregivers and patients using the transfer-aid equipment. The posture data were measured by a motion-capture system and converted to body-movement data. Furthermore, we exhaustively prepared scalar values representing the users’ body movements (e.g., the total velocity of a patient’s head and the total acceleration of a caregiver’s back) that span the vector space of product properties. Next, a semantic space describing a user’s motion when operating the transfer-aid equipment was constructed by the semantic differential technique (Osgood et al., 1957; Snider and Osgood, 1969), which is commonly used in Kansei engineering. In the semantic space, we included words that convey a caregiver’s impression of transfer-aid equipment being used by another caregiver, acquired through questionnaire responses to a video of the system. Prior to synthesis, the dimensionality of the semantic space was reduced by factor analysis of the questionnaire results. This analysis eliminates the redundancy in the selected words and clarifies the results. Finally, the quantifiable physical properties of the product derived from the caregiver and patient motions were related to the subjective impression of the product in use when watched by another caregiver. As the number of physical properties related to subjective impression is unknown, the appropriate physical properties were selected by stepwise-regression analysis using the Akaike information criterion (AIC). This process corresponds to the validation phase in standard methods, in the sense that appropriate physical quantities are chosen for the properties space. The obtained relationships between the physical quantities and users’ feelings were represented as delight maps Yanagisawa et al. (2016), in which users’ responses to a new product design can be estimated. The details and results of these processes are presented in the following sections.

2.2. Transfer-aid Equipment

The target products were four types of transfer-aid equipment that are easily available in Japan: a mobile electrical patient lift (KQ-781, Paramount Bed Co., Ltd, Tokyo, Japan), EasyGlideTM (5050, Handicare Group AB, Kista, Sweden), the KomawarisanTM (Hearts Eiko Co., Ltd, Kanagawa, Japan), and the Norisuke-sanTM (TNA-F, Idea System Co., Ltd, Nagano, Japan). When using the mobile electrical patient lift, the caregiver places a sling under the patient, then transfers the patient using an actuator that lifts the sling (see Fig. 1 (a)). Hereafter, this equipment is simply referred to as the lift. The EasyGlideTM forms a bridge between the bed and the wheelchair. The caregiver places the board beneath the patient and slides the patient onto the board, as shown in Fig. 1 (b). The KomawarisanTM is placed between the patient, who sits in a forward-bending posture, and the floor. The patient’s weight is supported while the caregiver rotates the patient about the device into the transfer position, as shown in Fig. 1 (c). Whereas most of the transfer-aid apparatuses are designed for weight-support of the transferred patient, the Norisuke-sanTM is a wheelchair that facilitates the easy transfer of a patient in the sitting position (see Fig. 1 (d)). When using this type of equipment, the caregiver detaches the seat from the wheelchair, places the seat under the patient, and attaches a sheet to the wheelchair for transfer.

Fig. 1 Four popular transfer-aid devices: (a) a lifting transfer device (the lift); (b) a sliding transfer device (EasyGlideTM); (c) a weight-support device (KomawarisanTM), and (d) a wheelchair for transferring patients in a sitting position (Norisuke-sanTM).
2.3. Recording of Caregiver and Patient Motions

First, we recorded videos of a caregiver transferring a patient manually and by each of the above devices. These videos were presented during the questionnaire session to reveal the caregiver’s impressions of the transfer-aid equipment when watching the motions and postures of the caregiver and the patient. To analyze the motions and postures that affect the caregiver’s impressions, the motion details were measured by a motion-capture system. In ergonomics studies, the physical burden of the caregiver or patient is typically estimated from electromyography and force measurements while capturing the activity by a motion-capture system. Our experiment omitted these devices because we aimed only to understand the subjective impressions evoked by watching the motions and postures of a caregiver and patient using the transfer-aid equipment. The physiological reactions associated with the physical burden were out of our scope in this paper, although they may relate to these impressions. Therefore, we used only the kinematic data obtained by the motion-capture system.

The experimental participants were two volunteers, the female assuming the patient role, the male assuming the caregiver role. The caregiver was required to transfer the patient from a bed to a wheelchair. Both participants had sufficiently practiced the use of the four transfer devices prior to measurement. The motion was recorded by a video camera placed on the front of the bed, so that both participants could be monitored. The caregiver and patient were outfitted with 41 and 42 markers, respectively, and the marker positions were measured by a Kestrel Digital Real Time System™ (Motion Analysis), which comprises sixteen optical cameras.

The measurement was carried out as follows. First, a wheelchair and the target transfer-aid device were placed in a predetermined position. At the start of the measurement, the patient participant lay supine on the bed, and the caregiver participant stood in a predetermined position. The measurement began with a signal, and the caregiver started the patient transfer. The measurement ended when the caregiver finished transferring the patient. There were five measurement cases: four cases using the different transfer equipment and the fifth case with manual transfer. Figure 2 shows the motion measurement procedure when the caregiver transferred the patient using the Komawarisan™.

2.4. Questionnaire for gauging the caregiver’s impressions

The caretaker’s impressions when watching another caregiver transfer a patent with and without transfer-aid equipment were reported in a questionnaire, and the semantic data were collected from the responses by the semantic-differential (SD) technique (Osgood et al., 1957). First, the researcher must prepare contrasting adjectives that adequately represent the target feelings of the user. The selected pairs of adjectives (listed in Table 1) were based on interviews and discussions with teachers at the Tokyo Ariake University of Medical and Health Sciences. It should be noted that these adjectives were chosen to measure the impression of the caregiver’s motion; therefore, they relate to motion only (e.g., whether the movements are attractive or unattractive). The details of the questionnaire, including these adjectives, are provided in the following sections.

2.4.1. Participants

Forty-four participants participated in the examination. All participants were undergraduate students at the Tokyo Ariake University of Medical and Health Sciences. They were aged 19 to 35 years and were physically healthy.
The lift (see 3 (a)).

The experiment was performed on personal computers. After reading the experimental instructions, the participants watched the five videos of the caregiver transferring the patient with or without transfer-aid equipment. The participants then re-watched each video and recorded their impressions on the 7-point scale. Each participant was asked to indicate their impression from the viewpoint of a caregiver.

2.5. Factor Analysis of Semantic Data

In the previous section, the scores of the 32 pairs of adjectives were obtained by the SD method. The constructed semantic space was slightly too large to relate the physical properties to the impressions. Therefore, the semantic space was reduced by the factor analysis method proposed by Weinreich (1958).

The number of factors in the factor analysis was decided by the Kaiser criterion (Kaiser, 1960), which defines the number of factors as the number of eigenvalues greater than 1 in the data correlation matrix. In our case, this number was estimated as six.

The factor analysis of the obtained semantic data was performed with six factors and maximum-likelihood estimation. The resultant data were rotated by a varimax rotation to remove their rotational uncertainty (Kaiser, 1958; Bishop, 2006). The adjectives comprising the six factors obtained by the factor analysis are listed in Table 2. This table shows the five adjectives with high factor loadings for each factor (pairs of adjectives with negative factor loadings are inverted from right to left). Note that the chosen adjectives for each factor have similar meanings. For example, the adjectives in factor 1 (‘elegant’, ‘dignified’, ‘warm’ and ‘affectionate’) relate to the thoughtfulness of the caregiver during the transfer. This analysis compressed the semantic space of the impressions of the caregiver’s motion during the patient transfer.

Figure 3 shows the mean scores of the 44 participants obtained in the previous section. The standard errors in each factor of the semantic space and each transfer method are also shown. These results reveal the impressions imparted by the caregiver’s motion when transferring the patient manually or by each device. For example, transfer motion using EasyGlide™ or the caregiver’s bare hands elicited feelings of thoughtfulness, which were lacking in transfer motion using the lift (see 3 (a)).

Table 1 Contrasting adjectives.

| Number of factor | Principle adjectives |
|------------------|----------------------|
| Factor 1         | elegant - inelegant  |
|                  | affectionate - unaffectionate |
|                  | dignified - undignified |
|                  | professional - unprofessional |
|                  | warm - cold           |
|                  | cold - uncool         |
|                  | thoughtfulness - unthoughtfulness |
|                  | trustworthiness - untrustworthiness |
|                  | natural - unnatural   |
|                  | easy - difficult      |
|                  | light - heavy         |
|                  | effortful - effortless |
|                  | quick - slow          |
|                  | compressed - loose    |
|                  | rhythmic - unrhythmic |

Table 2 Six factors obtained by factor analysis and the corresponding adjectives.

| Number of factor | Principle adjectives |
|------------------|----------------------|
| Factor 1         | elegant - inelegant  |
|                  | affective - unaffectionate |
|                  | dignified - undignified |
|                  | professional - unprofessional |
|                  | warm - cold           |
|                  | cool - uncool         |
|                  | thoughtfulness - unthoughtfulness |
|                  | trustworthiness - untrustworthiness |
|                  | natural - unnatural   |
|                  | easy - difficult      |
|                  | light - heavy         |
|                  | effortful - effortless |
|                  | quick - slow          |
|                  | compressed - loose    |
|                  | rhythmic - unrhythmic |

2.4.2. Materials

Participants watched four videos of a caregiver transferring a patient using various transfer-aid devices, and one video of a manual transfer. Participants were expected to study the motions of the caregiver and patient while using the lift, the EasyGlide™, the Komawarisan™, and the Norisukesan™ equipment and no equipment.

For the SD experiment, we prepared 32 pairs of adjectives (in Japanese, translated into English in Table 1) to be rated on a 7-point scoring scale. The extremities of the scale corresponded to a very strong impression, (e.g., very attractive or very unattractive). The placement of the favorable (unfavorable) adjective at the left (right) or right (left) extremity of the scale was randomly selected.

2.4.3. Procedure

The experiment was performed on personal computers. After reading the experimental instructions, the participants watched the five videos of the caregiver transferring the patient with or without transfer-aid equipment. The participants then re-watched each video and recorded their impressions on the 7-point scale. Each participant was asked to indicate their impression from the viewpoint of a caregiver.
2.6. Candidate Values Representing User Motions and Postures

The most difficult part of this study is the way of representing the motions and postures as a product property. The representation must be compatible with the semantic data obtained by Kansei engineering. Many studies have proposed techniques for representing human motions, such as the extraction of distinctive body motions from a series of people movements (Kovar and Gleicher, 2004; Beaudoin et al., 2008). These techniques, which are commonly employed in the computer graphics field, are too complex to synthesize with the semantic data represented by scalar values. Instead, we represented the motions and postures by scalar features calculated from the measured motions of human-body segments and the relative postures between these segments. We also considered the center-of-mass (CoM) motions of the whole body, which likely affect the overall impression conveyed to the watching caregivers. We omitted the small segments (hands, forearms, legs, and feet) because no meaningful features could be extracted from their small, complex motions. The features used in the analysis were obtained by the following process, and are listed at the end of this section.

The marker positions measured by the motion-capture system were converted into body-motion data of the participants by SIMM™ (Motion Analysis), a dedicated software for modeling the human musculoskeletal system. In SIMM, the human body motion was segmented into 41 parts corresponding to the skull, the clavicle, two scapulae, two upper arms, two ulnas, two radii, two wrists, two hands, 13 spinal segments, the pelvis, two thighs, two knees, two shins, two ankles, two feet, and two toes (see Fig. 4 (a)).

Furthermore, the CoM positions of 14 segmented body parts were estimated from the estimated positions of the 41 segmented body parts. For this estimation, we accessed the database of human-body properties published by the Digital Human Research Center, National Institute of Advanced Industrial Science and Technology. The 14 segments were the head, upper and lower torso, two upper arms, two forearms, two hands, two upper legs, two lower legs, and two feet (see Fig. 4(b)). The weights of these segments were calculated using the same database. From the calculated positions and weights of the body segments, we also estimated the CoM position of the whole body (Fig. 4 (c)).
Fig. 4 Human-body representation for analyzing the motions of participants. (a) 41 segmented body parts for representing the body motions of participants. (b) Center-of-mass positions of 14 segmented body parts and their weights. (c) Center-of-mass position of the whole body.

Ultimately, we obtained the positional changes of the CoMs of the 14 segmented body parts and the whole bodies of the patient and caregiver during transfer by hand and by using each of the four devices.

Time-series data of the user motions are difficult to synthesize with the semantic data. Therefore, in the synthesis phase, the motion data described in the previous section were transformed into meaningful scalar values that could be considered as candidate values representing the distinctive motions of the caregiver and patient, which must be considered when designing transfer-aid equipment. The candidate physical quantities representing the user motions are listed below:

- Work time (A).
- Mean distance between the CoMs of the caregiver and patient, calculated for the whole body CoMs (B1), the head CoMs (B2), and the upper and lower torso CoMs (B3 and B4, respectively).
- Increase in potential energy of the caregiver (C1), the patient (C2), and the total CoM of the caregiver and patient (C3). All calculations used the CoM position of the whole body.
- Integrated absolute values of the CoM velocities of the whole body, the head, the upper torso, and the lower torso, denoted as D1, D2, D3 and D4 respectively for the caregiver, and D5, D6, D7 and D8 respectively for the patient. The integrals were taken over the entire sampling time.
- Integrated absolute values of the CoM accelerations of the whole body, the head, the upper torso, and the lower torso, denoted as E1, E2, E3 and E4 respectively for the caregiver, and E5, E6, E7 and E8 respectively for the patient. The integrals were taken over the entire sampling time.
- Integrated absolute values of the CoM jerks (time derivatives of acceleration) of the whole body, head, upper torso, and lower torso, denoted as F1, F2, F3 and F4 respectively for the caregiver, and F5, F6, F7 and F8 respectively for the patient. The integrals were taken over the entire sampling time.
- Integrated absolute values of the inclination velocities of the head, upper torso, and lower torso, denoted as G1, G2 and G3 respectively for the caregiver, and G4, G5 and G6 respectively for the patient. The inclination velocities were calculated relative to the floor and were integrated over the entire sampling time.
- Integrated absolute values of the inclination accelerations of the head, upper torso, and lower torso, denoted as H1, H2 and H3 respectively for the caregiver, and H4, H5 and H6 respectively for the patient. The inclination accelerations were calculated relative to the floor and were integrated over the entire sampling time.
- Integrated absolute values of the inclination jerks of the head, upper torso, and lower torso, denoted as I1, I2 and I3 respectively for the caregiver, and I4, I5 and I6 respectively for the patient. The inclination jerks were calculated relative to the floor and were integrated over the entire sampling time.
- Maximum heights of the CoMs of the whole body, head, upper torso, and lower torso, denoted as J1, J2, J3 and J4 respectively for the caregiver, and J5, J6, J7 and J8 respectively for the patient.
- Minimum heights of the CoMs of the whole body, head, upper torso, and lower torso, denoted as K1, K2, K3 and K4 respectively for the caregiver, and K5, K6, K7 and K8 respectively for the patient.
- Maximum forward inclinations of the head, upper torso, and lower torso, denoted as L1, L2 and L3 respectively for the caregiver, and L4, L5 and L6 respectively for the patient.
- Minimum forward inclinations of the head, upper torso, and lower torso, denoted as M1, M2 and M3 respectively for the caregiver, and M4, M5, and M6 respectively for the patient.

Sixty physical quantities were calculated as scalar values. We emphasize that the chosen physical quantities vary among designers, so we prepared as many physical quantities as we could identify. Although factor analysis can also be applied to the properties space, we here considered only the semantic space because the reduced space of the physical properties is not easily interpretable.
Table 3 Resultant linear functions which represent the relationship between the factors comprised of adjectives and physical quantities describing motion of the caregiver and patient obtained by stepwise regression.

| Linear function | AIC | RMSE  | $y$ | $x_1$ | $x_2$ |
|-----------------|-----|-------|-----|-------|-------|
| $y = -5.95x_1 - 2.21x_2 - 4.65$ | 1578 | 8.59  | Factor 1 | E5 | E8 |
| $y = -5.75x_1 + 5.45$ | 1568 | 8.43  | Factor 2 | E4 | |
| $y = -6.98x_1 + 4.21$ | 1493 | 7.10  | Factor 3 | F7 | |
| $y = -4.08x_1 + 2.61x_2 + 6.72$ | 1283 | 4.39  | Factor 4 | J8 | G1 |
| $y = -3.41x_1 - 7.39$ | 1448 | 6.41  | Factor 5 | F7 | |
| $y = -1.85x_1 + 5.81$ | 948  | 2.06  | Factor 6 | F7 | |

2.7. Synthesis of Properties and Kansei Factors

In the previous subsection, we relate the space of properties to the distinctive motions of the caregiver and the patient. In this subsection, we relate this property space to the compressed semantic space describing the impressions of other caregivers. Among the candidate variables, the appropriate predictable variables for each factor in the semantic space were selected by stepwise regression using a forward-selection approach. The variable-selection criterion was the AIC, a commonly used criterion for evaluating a given model and comparing it against other models. The AIC also avoids the overfitting problem by maximizing the information quantity (Akaike, 1974). In this case, the AIC inferred the number of physical quantities, and the physical quantities that were most linearly related to each compressed semantic factor. For each semantic factor, the 44 participants yielded 220 samples. The AICs were obtained from the residuals of these samples and the linear regression results for each combination of the five compressed semantic factors and the set of 60 physical quantities. The set of physical quantities that minimized the AIC for a given compressed semantic factor was assumed to model the relationship between a caregivers’ motions when using transfer-aid equipment and the impressions they convey to other caregivers watching the motion. To ensure that the results were easily interpretable from the parameters of the linear regression results, the properties space was normalized in advance.

3. Resultant Kansei Model

Table 3 shows the stepwise regression results. Each $y$ denotes one of the factors obtained in subsection 2.5, and each $x_i$ is a physical quantity obtained in the previous subsection. In this case, the number of parameters never exceeded two. The AICs and the root mean squared errors (RMSE) of the linear regression results are also displayed in Table 3. These errors were mainly introduced by individual variations. The linear functions relating the adjective factors to the physical quantities describing the motions of caregivers and patients are called delight maps delight maps (Yanagisawa et al., 2016). The delight maps of the present study are displayed in Fig. 5. The contours delineate the values of each impression factor corresponding to the values of the physical quantities.

The linear relationships between the adjective factors and the physical quantities describing the motions of the caregiver and patient are interpreted below.

3.1. Linear function (1)

Linear function (1) in Table 3 relates factor 1, formed by the warm-cold adjective pair in Table 2, to the physical quantities E5 and E8. Factor 1 is supposedly associated with thoughtfulness, as mentioned above. E5 and E8 denote the integrated absolute values of the CoM accelerations of the whole body and upper torso, respectively, of the patient.

This linear relationship means that the caregiver’s impression of thoughtfulness decreases with increasing values of E5 and E8. The integrated absolute value of the acceleration can be interpreted as the number of start-and-stop motions of the patient. This value is thought to be closely related to the number of phases required to transfer a patient to the wheelchair. It also increases during rapid movement of the patient. According to this relationship, caregivers perceive carelessness when they see a patient being transferred by complicated and rough procedures, even over small distances. This result also implies that whole-body and upper-torso movements of the patient both affect the caregiver’s impression.

Judging from Fig. 5 (a), EasyGlideTM imparts an impression of thoughtfulness by inducing few motions of the patient’s upper body. In contrast, the lift, the KomawarisanTM, and the NorisykesanTM were regarded as less thoughtful than manual transfer of the patient. The lift imparted the worst impression of thoughtfulness, possibly because this aid requires lifting and lowering a patient many times.

Based on this result, the designer must consider the perceived discomfort of a complex procedure to patients.
3.2. Linear function (2)

Linear function (2) in Table 3 relates factor 2, formed by the desirable-undesirable adjectives in Table 2, to the physical quantity E4. These adjectives include ‘good’, ‘amazing’, and ‘desirable’, and presumably indicate a favorable impression. E4 is the integrated absolute value of the CoM acceleration of the lower torso of the caregiver.

This linear relationship means that the caregiver’s motion becomes less favorable as E4 increases. E4 can be interpreted as the number of lower-torso movements of the caregiver when transferring the patient to the wheelchair.

This result is assumed to reflect the inconvenience of crouching down when transferring the patient, as already mentioned by the participants in preliminary interviews. When a caregiver transfers a patient using the lift or the Komawarisan™, crouching down is unavoidable, and presumably imparts an unfavorable impression to the observing caregivers (see Fig. 5 (b)).

This result is very important in the design of transfer-aid equipment. Designers of such equipment should recognize that caregivers prefer equipment that minimizes the number of crouches during use.

3.3. Linear function (3)

Linear function (3) in Table 3 relates factor 3 to the physical quantity F7. Factor 3 combines the adjectives ‘simple’, ‘uncomplicated’, ‘rhythmic’, and ‘easy’, and supposedly indicates that the equipment is easy to use. F7 corresponds to the integrated absolute value of the CoM jerk of the upper torso of the patient, which describes the smoothness of the motion (in this case, the motion of the patient’s upper torso).

The patient’s motion destabilizes when the transfer-aid equipment is difficult to use. The results suggest that the participants sensed this instability when viewing the motion, and therefore focused on the upper-torso motion of the patient.

3.4. Linear function (4)

Linear function (4) in Table 3 relates factor 4 to the physical quantities J8 and G1. Factor 4 comprises the adjectives ‘unburdened’, ‘effortless’, and ‘light’, which reflect the perceived burden on the caregiver. J8 corresponds to the maximum
height of the CoM of the patient’s lower torso, and G1 corresponds to the integrated absolute value of the inclination velocity of the caregiver’s head.

This relationship is relatively easy to interpret. At a large maximum height of the patient’s lower torso, the caregiver must raise the patient; this activity was perceived as burdensome by the participants of the SD test. Lifting of patients is a well-known cause of lower-back injuries (Yassi et al., 2001). Meanwhile, the integrated absolute value of the head inclination velocity reflects the changing head posture of the caregiver during the transferring motion. The forward-bending posture burdens the lower back, and lower-back pain is a common occupational hazard of caregivers. Daynard et al. (2001) reported that when an unusual forward-flexed posture is sustained over a long period, such as when readying the equipment for use, the cumulative spinal loads pose a health risk. We speculate that the inclination of the head better represents the forward-bending posture of the caregiver than inclination of the upper torso. The participants of the SD test similarly sensed this motion as burdensome for the caregiver.

During the manual transfer, the caregiver was required to raise the body of the patient, which involved a deep forward-bending posture when holding and releasing the patient. For this reason, transference without equipment imparted a poor impression of effort (see Fig. 5 (d)).

3.5. Linear function (5)
Linear function (5) in Table 3 relates factor 5 to the physical quantity F1. Factor 5 embraces the adjectives ‘stable’, ‘trustworthy’, and ‘safe for a patient’, and supposedly represents the reliability of the equipment. F1 corresponds to the integrated absolute value of the CoM jerk of the caregiver.

Because F1 can be interpreted as the smoothness of the caregiver’s motion, the participants of the SD test probably sensed the unreliability of the caregiver’s unsteady motion, which exposes the patient to possible harm.

3.6. Linear function (6)
Linear function (6) in Table 3 relates factor 6 to the physical quantity F7. The adjectives in Factor 6 are ‘rhythmic’, ‘fast’, and ‘simple’, which presumably impart an impression of speed. F7 corresponds to the integrated absolute value of the CoM jerk of the patient’s upper torso. This linear function is identical to linear function (3), reflecting the similar meanings of factors 3 and 6. When an additional parameter was chosen for each factor, we confirmed that the second parameter differed in the two-parameter linear functions of factors 3 and 6.

4. Conclusion
In this paper, we derived a delight map that represents the linear relationship between the motions of a caregiver and patient as the patient is transferred from a bed to a wheelchair, and the feelings of other caregivers watching this motion. This relationship elucidates the causes of these feelings, and reveals the factors that would increase the penetration rate of transfer-aid equipment by eliminating the psychological barrier to its use. These factors should be considered by designers of transfer-aid equipment. According to the factor analysis in Section 2.5, caregivers experience six kinds of feelings when viewing the use of transfer-aid equipment by other caregivers. Furthermore, as confirmed on the resultant delight maps derived from the variables selected in Section 2.7, these kinds of feelings relate to specific movements of the caregiver or patient. The meanings of these linear relationships were explained intuitively in Section 3.

The most common criteria in the design of transfer-aid equipment are reducing the physical load and avoiding caregiver injury. From this viewpoint, caregivers should avoid movements that cause large, instantaneous spinal loading or cumulative spinal loading (Daynard et al. (2001). Above, we reported that such movements impart a sense of physical burden to caregivers. This means that caregivers empirically understand or have been taught that such movements endanger their physical health, and that merely watching such motions instils a sense of physical burden. Interestingly, caregivers viewed the equipment not only from a physical-burden perspective, but also from other distinct perspectives, such as simplicity of using the equipment and patient safety. The most distinctive feeling obtained by the factor analysis was perceived to be lack of thoughtfulness. As implied in the above discussion, this feeling seemingly increased when the patient was moved roughly and often, and may explain (at least partly) why caregivers hesitate to use transfer-aid equipment. The design of transfer-aid equipment from this viewpoint has not been previously discussed in ergonomic research. When designing new aid equipment from a biomechanical viewpoint, the most important concern is reducing the physical burden of the caregivers. To encourage the use of these technologies, the designer must also consider users’ feelings; in particular, a more patient-centered design is required.
Our present work is a first attempt to relate user motions during the use of transfer-aid equipment to the impressions of other caregivers watching those motions. The analysis applies Kansei engineering and visualizes the relationships on delight maps. Our results revealed the caregivers’ impressions of the transfer-aid equipment, but several problems must be solved in future work. First, we assumed a linear relationship between the semantics and the properties spaces. Although we obtained meaningful results in this paper, linearity is a strong assumption. To obtain a more reliable Kansei relationship, we should consider a nonlinear relationship between the semantic and properties spaces. The second problem is the number of samples needed to construct the spaces. Owing to the difficulty of obtaining the motion data of the transfer-aid equipment by a motion-capture system, the present paper considered only four products. To collect many samples efficiently, we require a system that more easily captures the motion data. On the other hand, new semantic data concerning other transfer-aid equipment should be relatively easy to acquire, because we already know the appropriate adjectives associated with user motions.

Finally, although we obtained the impressions of caregivers viewing the specific motions and postures of caregivers and patients, which impressions motivate or demotivate the caregivers’ use of transfer-aid equipment, and the extent to which these impressions affect their motivations, remain uncertain. Elucidating these associations requires a psychological approach. For example, self-determination theory recognizes two classes of motivation: intrinsic and extrinsic (Deci and Ryan, 1985, 2000). Extrinsic motives gradually shift toward intrinsic motivations, which can be external, introjected, identified, or integrated regulations, depending on the stage of internalization. Internalized motivation is associated with consumers’ satisfaction and persistence of the motivation. Understanding which motivation belongs to which stage is important when deciding motivation-influenced policies. From this viewpoint, any motivations elicited by the impressions of transfer-aid equipment in our present findings are likely to be internalized or intrinsic motivations. Such motivations will override extrinsic motivations such as enforcement by law. By comparing the different impressions of caregivers who usually use transfer-aid equipment and those who have never used it, we can know the impressions that motivate the users. Furthermore, studying how these impressions are formed would reveal the type of motivation. In future work, we will resolve these uncertainties through psychological models based on our present findings.

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References

Akaike, H., A new look at the statistical model identification, IEEE Transactions on Automatic Control, Vol.19, No.6 (1974), pp.716–723.
Analee Yassi, M. and Tait, D., Effectiveness of installing overhead ceiling lifts: Reducing musculoskeletal injuries in an extended care hospital unit, Workplace Health & Safety, Vol.50, No.3 (2002), pp.120.
Andersen, L. L., Burdorf, A., Fallentin, N., Persson, R., Jakobsen, M. D., Mortensen, O. S., Clausen, T., and Holtermann, A., Patient transfers and assistive devices: prospective cohort study on the risk for occupational back injury among healthcare workers, Scandinavian Journal of Work, Environment & Health, Vol.40, No.1 (2014), pp.74–81.
Baptiste, A., Boda, S. V., Nelson, A. L., Lloyd, J. D., and Lee, W. E., Friction-reducing devices for lateral patient transfers: a clinical evaluation, Workplace Health & Safety, Vol.54, No.4 (2006), pp.173.
Beaudoin, P., Coros, S., van de Panne, M., and Poulin, P., Motion-motif graphs, In Proceedings of the 2008 ACM SIGGRAPH/Europographics Symposium on Computer Animation, pages 117–126, Eurographics Association, (2008).
Bell, F., Dalgity, M., Fennell, M.-J., and Aitken, R., Hospital ward patient-lifting tasks, Ergonomics, Vol.22, No.11 (1979), pp.1257–1273.
Buckle, P., Epidemiological aspects of back pain within the nursing profession, International journal of nursing studies, Vol.24, No.4 (1987), pp.319–324.
Chen, M. C., Hsu, C. L., Chang, K. C., and Chou, M. C., Applying kansei engineering to design logistics services – a case of home delivery service, International Journal of Industrial Ergonomics, Vol.48, (2015), pp.46–59.

Chou, J. R., A kansei evaluation approach based on the technique of computing with words, Advanced Engineering Informatics, Vol.30, No.1 (2016), pp.1–15.

Collins, J. W., Wolf, L., Bell, J., and Evanoff, B., An evaluation of a” best practices” musculoskeletal injury prevention program in nursing homes, Injury Prevention, Vol.10, No.4 (2004), pp.206–211.

Corlett, E. N. and Corlett, E. N., The guide to the handling of patients, National Back Pain Association in collaboration with the Royal College of Nursing, (1992).

Daynard, D., Yassi, A., Cooper, J., Tate, R., Norman, R., and Wells, R., Biomechanical analysis of peak and cumulative spinal loads during simulated patient-handling activities: a substudy of a randomized controlled trial to prevent lift and transfer injury of health care workers, Applied ergonomics, Vol.32, No.3 (2001), pp.199–214.

Deci, E. L. and Ryan, R. M., Intrinsic motivation and self-determination in human behavior, New York and London: Plenum, (1985).

Deci, E. L. and Ryan, R. M., The “what” and “why” of goal pursuits: Human needs and the self-determination of behavior, Psychological inquiry, Vol.11, No.4 (2000), pp.227–268.

Demirtas, E. A., Anagun, A. S., and Koksal, G., Determination of optimal product styles by ordinal logistic regression versus conjoint analysis for kitchen faucets, International Journal of Industrial Ergonomics, Vol.39, No.5 (2009), pp.866–875.

Engkvist, I.-L., Evaluation of an intervention comprising a no lifting policy in australian hospitals, Applied Ergonomics, Vol.37, No.2 (2006), pp.141–148.

Griffith, R. and Stevens, M., Manual handling and the lawfulness of no-lift policies, Nursing Standard, Vol.18, No.21 (2004), pp.39–43.

Hoogendoorn, W. E., van Poppel, M. N., Bongers, P. M., Koes, B. W., and Bouter, L. M., Physical load during work and leisure time as risk factors for back pain, Scandinavian journal of work, environment & health, (1999), pp.387–403.

Huang, Y., Chen, C.-H., and Khoo, L. P., Kansei clustering for emotional design using a combined design structure matrix, International Journal of Industrial Ergonomics, Vol.42, No.5 (2012), pp.416–427.

Ishihara, S., Kansei engineering procedure and statistical analysis, In International Conference on Affective Human Factors Design, pages 27–29, (2001).

Ishihara, S., Ishihara, K., Nagamachi, M., and Matsubara, Y., An automatic builder for a kansei engineering expert system using self-organizing neural networks, International Journal of Industrial Ergonomics, Vol.15, No.1 (1995), pp.13–24.

Ishihara, S., Ishihara, K., Matsubara, Y., and Nagamachi, M., Analysis of kansei structure on women’s suits design by neural networks, Manufacturing Agility and Hybrid Automation, (1996), pp.85–88.

Kaiser, H. F., The varimax criterion for analytic rotation in factor analysis, Psychometrika, Vol.23, No.3 (1958), pp.187–200.

Kaiser, H. F., The application of electronic computers to factor analysis., Educational and psychological measurement, Vol.20, No.1 (1960), pp.141–151.

Komazawa, T. and Hayashi, C., A statistical method for quantification of categorical data and its application to medical science, In Decision Making and Medical Care, (1976).

Kovar, L. and Gleichler, M., Automated extraction and parameterization of motions in large data sets, In ACM Transactions on Graphics (TOG), volume 23, pages 559–568, ACM, (2004).
Krishnan, R. H. and Pugazhenthi, S., Mobility assistive devices and self-transfer robotic systems for elderly, a review, Intelligent Service Robotics, Vol.7, No.1 (2014), pp.37–49.

Levy, P., Beyond kansei engineering: The emancipation of kansei design, International Journal of Design, Vol.7, No.2 (2013).

Lokman, A. M., Design & emotion: The kansei engineering methodology, Malaysian Journal of Computing, Vol.1, No.1 (2010), pp.1–11.

Martin, P. J., Harvey, J. T., Culvenor, J. F., and Payne, W. R., Effect of a nurse back injury prevention intervention on the rate of injury compensation claims, Journal of safety research, Vol.40, No.1 (2009), pp.13–19.

Moody, J., McGuire, T., Hanson, M., and Tigar, F., A study of nurses’ attitudes towards mechanical aids, Nursing Standard, Vol.11, No.4 (1996), pp.37–42.

Nagamachi, M., Kansei engineering: a new ergonomic consumer-oriented technology for product development, International Journal of industrial ergonomics, Vol.15, No.1 (1995), pp.3–11.

Nagamachi, M., Kansei engineering and rough sets model, In Rough Sets and Current Trends in Computing, pages 27–37, Springer, (2006).

Nelson, A., Fragala, G., and Menzel, N., Myths and facts about back injuries in nursing, The American Journal of Nursing, Vol.103, No.2 (2003), pp.32–40.

Nelson, A., Lloyd, J. D., Menzel, N., and Gross, C., Preventing nursing back injuries: redesigning patient handling tasks, Workplace Health & Safety, Vol.51, No.3 (2003), pp.126.

Nelson, A., Owen, B., Lloyd, J. D., Fragala, G., Matz, M. W., Amato, M., Bowers, J., Moss-Cureton, S., Ramsey, G., and Lentz, K., Safe patient handling and movement: Preventing back injury among nurses requires careful selection of the safest equipment and techniques. the second of two articles., The American Journal of Nursing, Vol.103, No.3 (2003), pp.32–43.

Osgood, C. E., Suci, G. J., and Tannenbaum, P. H., The measurement of meaning, University of Illinois Press, (1957).

Retsas, A. and Pinikahana, J., Manual handling activities and injuries among nurses: an australian hospital study, Journal of advanced nursing, Vol.31, No.4 (2000), pp.875–883.

Schoenfisch, A. L., Lipscomb, H. J., Pompeii, L. A., Myers, D. J., and Dement, J. M., Musculoskeletal injuries among hospital patient care staff before and after implementation of patient lift and transfer equipment, Scandinavian journal of work, environment & health, (2013), pp.27–36.

Schütte, S. T., Eklund, J., Axelsson, J. R., and Nagamachi, M., Concepts, methods and tools in kansei engineering, Theoretical Issues in Ergonomics Science, Vol.5, No.3 (2004), pp.214–231.

Snider, J. G. and Osgood, C. E., Semantic differential technique: A sourcebook, Aldine Chicago, (1969).

Stobbe, T. J., Plummer, R. W., Jensen, R. C., and Attfield, M. D., Incidence of low back injuries among nursing personnel as a function of patient lifting frequency, Journal of Safety Research, Vol.19, No.1 (1988), pp.21–28.

Trinkoff, A. M., Brady, B., and Nielsen, K., Workplace prevention and musculoskeletal injuries in nurses, Journal of Nursing Administration, Vol.33, No.3 (2003), pp.153–158.

Weinreich, U., Travels through semantic space, Word, Vol.14, No.2-3 (1958), pp.346–366.

Yanagisawa, H., Nakano, S., and Murakami, T., A proposal of kansei database framework and kansei modelling methodology for the delight design platform, Journal of Integrated Design and Process Science, Vol.20, No.2 (2016), pp.78–84.

Yassi, A., Cooper, J., Tate, R., Gerlach, S., Muir, M., Trottier, J., and Massey, K., A randomized controlled trial to prevent patient lift and transfer injuries of health care workers, Spine, Vol.26, No.16 (2001), pp.1739–1746.

Zhuang, Z., Stobbe, T. J., Collins, J. W., Hsiao, H., and Hobbs, G. R., Psychophysical assessment of assistive devices for transferring patients/residents, Applied Ergonomics, Vol.31, No.1 (2000), pp.35–44.