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Physical gestures for abstract concepts: Inclusive design with primary metaphors

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ABSTRACT

Designers in inclusive design are challenged to create interactive products that cater for a wide range of prior experiences and cognitive abilities of their users. But suitable design guidance for this task is rare. This paper proposes the theory of primary metaphor and explores its validity as a source of design guidance. Primary metaphor theory describes how basic mental representations of physical sensorimotor experiences are extended to understand abstract domains. As primary metaphors are subconscious mental representations that are highly automated, they should be robustly available to people with differing levels of cognitive ability. Their proposed universality should make them accessible to people with differing levels of prior experience with technology. These predictions were tested for 12 primary metaphors that predict relations between spatial gestures and abstract interactive content. In an empirical study, 65 participants from two age groups (young and old) were asked to produce two-dimensional touch and three-dimensional free-form gestures in response to given abstract keywords and spatial dimensions of movements. The results show that across age groups in 92% of all cases users choose gestures that confirmed the predictions of the theory. Although the two age groups differed in their cognitive abilities and prior experience with technology, overall they did not differ in the amount of metaphor-congruent gestures they made. As predicted, only small or zero correlations of metaphor-congruent gestures with prior experience or cognitive ability could be found. The results provide a promising step toward inclusive design guidelines for gesture interaction with abstract content on mobile multitouch devices.

1. Introduction

Recent trends in developing interactive products pose opportunities and challenges for inclusive design. Two of these trends involve new interaction possibilities like multitouch and gesture input. Since the Apple iPhone brought multi-touch interaction to the mass consumer market, this new way of interacting with devices with one or more fingers directly on the surface of the display has become increasingly popular. The technology finds its way into a large variety of mobile electronic consumer products, ranging from cell phones, PDAs and digital cameras to navigation systems, music players, and netbook computers. At the same time, these devices become capable of sensing movement in space, which makes them fit for three-dimensional gesturing. Again, the iPhone is leading the charge for commercial viability and applications of 3D gestures with the device range from shifting between display modes (i.e. portrait versus landscape), navigation in lists, and more complex physical control in interactive games. In the following, we speak of *2D touch gestures* when movement patterns are performed with the user's fingers or hand on the surface of a device, and *3D free-form gestures* when the whole device is relocated or turned in space by meaningful arm and hand movements of the user (cf. Saffer, 2008).

These advancements in interaction paradigms go hand in hand with a change in the content that is manipulated. While early mobile devices were used to manipulate the physical world or representations of it (e.g. speech communication via the mobile phone, taking pictures of the world with a digital camera), they are increasingly used to also manipulate abstract content. There is a rich source of applications for managing personal finances, for social networking, for learning, for time and project management, for understanding modern art, for shopping, for text and picture editing as well as gaming. Some of these applications might require the user to navigate through time, to assign importance to screen objects, to evaluate, for example, the quality of the food or the friendliness of the staff in a restaurant, to track sports scores, to manage social relations and so on. Common to all these demands is that they require the manipulation of abstract data (importance,

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valence, similarity, time) with essentially physical means (button presses, 2D touch gestures, 3D free-form gestures).

Although manufacturers' marketing departments are not getting tired of advertising gesture interaction as very "natural", "easy" and "intuitive" to use, the trend towards new interaction paradigms and contents could be a potential problem for inclusive design. Previous research has shown that older users (60+ years) in particular have problems when interacting with existing everyday technology (e.g. Fisk et al., 2009; Czaja and Lee, 2007) and that these problems can be attributed to the physical, perceptual and cognitive changes that accompany the normal aging process. Older users frequently report problems related to small interaction elements, e.g. buttons and text on displays, an overload of functions, and unnecessary menus which are hard to understand and recall (cf. in the context of mobile phone usage: Kurniawan, 2008). Usually, performance with technology is lower for older than for younger users (Blackler et al., 2009; Fisk et al., 2009; Lewis et al., 2008). Older users are prone to make more errors and be slower in using devices (Fisk et al., 2009; Lewis et al., 2008). Recent findings imply that this decline in performance is not a matter of ageing per se but rather a function of cognitive ability and prior experience with the technology in question (Blackler et al., 2009; Langdon et al., 2009). Other research proposes the existence of technology generations: people of different ages have different prior levels of exposure to specific types of technology, thus making inclusive design more difficult (Docampo Rama, 2001).

In the area of gesture interaction the benefits and drawbacks for inclusive design still have to be researched. Gesture-based interaction – either through 2D touch gestures or 3D free gesturing – can bring several advantages to inclusive design where traditional input paradigms fall behind: gesture interaction is potentially eyes-free (can be performed without having to watch the screen closely), button-free (no need to precisely hit small buttons), and silent (less obtrusive than e.g. voice input). In addition, a cumbersome keypad lock system for mobile devices, where the user first has to unlock the keypad through a combination of arbitrary button presses before the interaction and lock the keypad again in a similar way after the intended interaction, becomes unnecessary when using gesture interaction, because gesture patterns are not likely to occur by accident (Kallio et al., 2010). However, gesture interaction also has its drawbacks, such as the lack of haptic feedback or the loss of cues and affordances, which might render this type of interaction particularly difficult for elderly users. Potential benefits and drawbacks of gesture interaction for inclusive design are discussed in more detail in Stößel and Blessing (2009). Recent findings for user-generated gestures imply that older users differ from younger users in being more diverse in their proposed gestures than younger users, that they rely stronger on single-finger (versus multi-finger) interaction and employ more symbolic gestures (compared to purely spatial gestures) than younger users (Stößel and Blessing, 2010).

As there is good reason to believe that older users differ from younger users in how effectively and efficiently they use new forms of technology (Czaja et al., 2006), the goal of inclusive design is to find ways of designing interaction that is "usable by people with the widest range of abilities within the widest range of situations without the need for special adaptation or design" (BS7000-6; BSI, 2005). If inclusive design is to be pursued within the sketched framework of gesture interaction for abstract domains, there need to be answers to questions like these: How can designers quickly devise mappings between physical gestures and abstract concepts? How can these mappings be made inclusive?

This paper suggests and introduces a top-down approach that involves the concepts of image schemas and primary metaphors as the theoretical basis for designing physical-to-abstract mappings in gestures. This approach is chosen because it promises to lead to quick and effective results. It follows an empirical study, in which the predictions of the theory are tested for 12 physical-to-abstract mappings. It is also tested whether these mappings are as robust to variations in cognitive ability and universal for different levels of prior experience as is predicted by the theory. The results are summarised in the light of designing inclusive gestures for mobile devices using primary metaphor theory. In the following, we use *mobile device* as a generic term for a broad range of handheld electronic devices like mobile phones, mp3-players, digital cameras, navigation systems, PDAs or eBook readers. Because we investigate abstract concepts (such as similarity, importance and power) and different mobile technologies are converging into multi-purpose devices, we assume that the results of the study can be applied to different kinds of mobile devices that are capable of sensing 2D touch or 3D free-form gesture input.

2. Image schemas and primary metaphors

The next sections explore the notions of image schemas and primary metaphor in more detail before their promises for designing inclusive interactions are derived.

2.1. Image schemas

The term *image schema* was introduced by the philosopher Mark Johnson: "An image schema is a recurring, dynamic pattern of perceptual interactions and motor programs that gives coherence and structure to our experience" (1987, p. xiv). A prominent image schema is the UP–DOWN image schema that forms the basis of "thousands of perceptions and activities we experience every day, such as perceiving a tree, our felt sense of standing upright, the activity of climbing stairs, forming a mental image of a flagpole, measuring the children's heights, and experiencing the level of water rising in the bathtub" (Johnson, 1987, p. xiv).

The example shows that image schemas are not reduced to the visual domain. They can also be derived from acoustic, haptic, and kinaesthetic experiences. Recurring and similar interactions with the world leave traces of these experiences in the brain (Fig. 1). Crucially, these traces bear a resemblance to the perceptual and action processes that generated them, and are highly abstract. The experience with gravity and upright objects shapes the mental representation of an UP–DOWN image schema. Once an image schema is formed, it can be instantiated in different ways. A user interface designer can instantiate the UP–DOWN image schema in a vertical slider, in a vertical lever, or by putting vertical arrows on buttons.

The experiential acquisition of other image schemas is similar: The image schema NEAR–FAR derives from the experience of reaching; FRONT–BACK develops from the default direction of visual perception and movement; and CENTRE–PERIPHERY is informed by the bodily relations between the trunk and the extremities. Although the focus here is on spatial image schemas, there are other image schemas deriving from force-dynamic experiences like ATTRACTION, BLOCKAGE, DIVERSION, or they are derived from salient object characteristics like BIG–SMALL, BRIGHT–DARK, HEAVY–LIGHT.

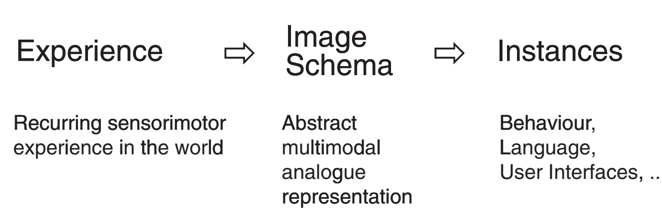

Fig. 1. Acquisition, representation, and instantiation of image schemas.

Image schemas originate in philosophical and linguistic analyses (Hampe, 2005; Johnson, 1987; Lakoff, 1987) and their psychological reality has been confirmed by research in the cognitive (neuro-) sciences (Gibbs, 2005; Gibbs and Colston, 1995; Rohrer, 2005) and developmental psychology (Mandler, 1992, 2004, 2005). Altogether about 40 of such image schemas are documented (for an overview see Hurtienne, 2009). Image schemas are thought to be universal and underlying more complex mental representations.

In interaction design image schemas can be used for simple physical-to-physical mappings. In the game *Doodle Jump* for the iPhone, for example, the LEFT–RIGHT image schema is instantiated. A small character needs to jump from one platform to another, which are suspended in mid-air. Control is achieved by tilting the device leftwards and rightwards to move the character to the left and to the right. The focus in this paper, however, is on physical-to-abstract mappings. For these mappings, the idea of *primary metaphor* needs to be discussed.

2.2. Primary metaphor

A primary metaphor is a conceptual association of an image schema with an abstract target domain. Primary metaphors arise through repeated co-occurrences of concrete physical sensorimotor experiences (i.e. events that trigger image schema representations) with more abstract subjective experiences or judgements (Grady, 1997a,b). The vertical level of a liquid in a container, for example, correlates with the quantity of the liquid; the vertical extension of a pile of papers correlates with the amount of paper in the pile, and so on. Hence, in many contexts, verticality (UP–DOWN) is connected to quantity. In learning about the world as children, these connections between domains are automatically learned as well. Through repeated experience with different quantities in different contexts, these connections become generalised. As a result, verticality is connected with quantities of all sorts. This then also extends to non-physical quantities that are conceptualised on an UP–DOWN axis, as the linguistic expressions *the inflation rose by 5%* or *He is underage* illustrate. The conceptual connection between the domains of verticality and quantity is the primary metaphor. Here, the notation of primary metaphors follows the convention TARGET DOMAIN IS IMAGE SCHEMA, hence in the example: MORE IS UP – LESS IS DOWN.

Like image schemas, primary metaphors are assumed to operate subconsciously and are instantiated in behaviour, imagination, language, and eventually user interfaces (Fig. 2). The conceptual metaphor MORE IS UP – LESS IS DOWN is not only instantiated in linguistic expressions but also in charts, for example showing the development of share prices of a company. In user interfaces, the primary metaphor MORE IS UP – LESS IS DOWN can be found in a vertical sliding gesture for controlling the volume of speakers, a water tap, or a spin box, making physical-to-abstract mappings possible.

Other correlations in experience form other primary metaphors. For instance, when we walk along a path, waypoints in front of us will be reached at a later time from now. Waypoints that lie behind us are those that we have passed at an earlier time. This pervasive experience grounds the metaphor THE FUTURE IS IN FRONT – THE PAST IS BEHIND. The metaphor is instantiated, for example, in expressions like *He has a great future in front of him. That's all behind us now*. Similarly, familiarity tends to co-occur with physical closeness, forming the metaphor FAMILIAR IS NEAR – UNFAMILIAR IS FAR drawing on the NEAR–FAR image schema. It is instantiated in sentences like *I feel close to him. He was a distant stranger only*.

About 250 of such primary metaphors that combine image schemas with more abstract concepts have been documented. Often they are the results of linguistic studies (cf. Hurtienne, 2009). The promises of primary metaphor theory are manifold. Applying the theory to user interface design allows for a large number of guidelines of possible physical-to-abstract mappings that are potentially suitable for inclusive design.

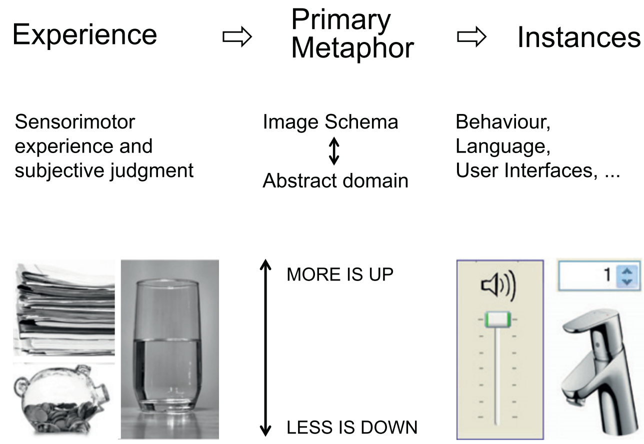

Fig. 2. Acquisition and instantiation of primary metaphors, with examples.

2.3. The promise for inclusive interaction design

Two characteristics of primary metaphors are important for inclusive user interface design. First, primary metaphors result from repeated correlations of sensorimotor experience in the world. This makes them fundamental units of knowledge that are shared by a large range of people with otherwise different experiential backgrounds. Metaphoric mappings of physical source domains to abstract target domains should thus be equally prevalent in different technology generations. Gestures for abstract concepts based on primary metaphors should therefore be equally appropriate for people with varying degrees of prior experience with technology.

Second, the frequent, pervasive and ongoing repetition of the experiences forming primary metaphors should make them easily accessible to human information processing. That is, their retrieval from memory should have become automated and subconscious. Thus, a decline in conscious cognitive abilities should affect the processing of metaphors to a lesser degree, and thus interaction based on primary metaphors should be largely independent from conscious abilities like the speed of information processing.

If these theoretical assumptions are correct, then the theory is able to predict mappings of physical gestures to abstract data. Moreover, these mappings should be independent from prior experience with technology; they should be robust against the decline of cognitive abilities; and therefore they should be universally applicable across age groups. These assumptions of primary metaphor theory were tested in an empirical study – to our knowledge the first of its kind in inclusive design.

From documentations of cognitive linguistic analyses, 12 primary metaphors were selected and tested in the context of gesture interaction with a mobile device. Participants received target words from abstract domains (e.g. *future*, *powerful*) and a spatial dimension they should use for making a gesture (e.g. UP–DOWN, NEAR–FAR). Gestures were made either as 2D touch gestures or 3D free-form gestures. The hypotheses were as follows:

1. Primary metaphors are valid in the domain of gesture interaction, i.e. the proportion of participants making metaphor-congruent gestures (e.g. UP for *good*, instead of DOWN for *good*) is well above chance level (50%).
2. The proportion of metaphor-congruent gestures is the same for 2D touch or 3D free-form gestures.

3. The proportion of metaphor-congruent gestures does not differ between a young and an old age group.
4. Although both age groups differ in their prior experience with technology and their cognitive abilities, the amount of individual agreement with metaphors shows only low correlations with prior technology experience or with cognitive ability.

The first two hypotheses validate the claim of primary metaphor theory for the domain of gesture interaction. The last two hypotheses test the value of the theory for inclusive design. The following sections describe the methods in more detail.

3. Method

The study was set up as a within-subject comparison of 2D touch and 3D free-form gestures for 12 primary metaphors. Age, technology experience, and cognitive ability varied between subjects. The dependent variable was the proportion of metaphor-congruent gestures made for a specific target domain. The following sections give details on which metaphors were used in the study, the participants, the procedure, and the measures employed.

3.1. Primary metaphors used in the study

A number of primary metaphors are well documented through cognitive linguistic analyses of their instantiations in language (e.g. Baldauf, 1997; Grady, 1997a,b; Jäkel, 2003; Kövecses, 2002, 2005; Lakoff and Johnson, 1980, 1999) and earlier work has successfully applied a selection of these metaphors to derive design guidelines for graphical and tangible user interfaces (Hurtienne, 2009; Hurtienne and Blessing, 2007; Hurtienne et al., 2009; Lund, 2003). Following this approach of using already documented primary metaphors in the domain of user interface design, 12 primary metaphors were selected. The selection was based on two criteria: the primary metaphors had to be useful for the design of gestural interaction and there should be a well documented number of linguistic findings for these metaphors. As gestures take place in space, primary metaphors based on image schemas marking spatial location and spatial movements were of particular interest. This included primary metaphors of the image schemas CENTRE–PERIPHERY, FRONT–BACK, NEAR–FAR, and UP–DOWN. The metaphors are listed below, together with examples that illustrate their linguistic instantiations and the sources where these metaphors are documented.

- IMPORTANT IS CENTRAL – UNIMPORTANT IS PERIPHERAL, as in *What is central here? That's just a peripheral issue*. (Lakoff et al., 1991)
- THE FUTURE IS IN FRONT – THE PAST IS BEHIND, as in *He has a great future in front of him. That's all behind us now*. (Lakoff and Johnson, 1999)
- PROGRESS IS FORWARD MOVEMENT – UNDOING PROGRESS IS BACKWARD MOVEMENT, as in *Let's keep moving forward. We need to backtrack*. (Lakoff, 1990)
- SIMILAR IS NEAR – DIFFERENT IS FAR, as in *A and B are close, but they are by no means identical. The difference between A and B is vast*. (Lakoff et al., 1991)
- FAMILIAR IS NEAR – UNFAMILIAR IS FAR, as in *I feel close to him. He distances himself*. (Lakoff et al., 1991)
- CONSIDERED IS NEAR – NOT CONSIDERED IS FAR, as in *My companion put it to me that an initiative must now be taken. For the Kaszubes and Poles of Danzig Poland was a distant idea only*. (Baldauf, 1997; BNC, 2007)
- GOOD IS NEAR – BAD IS FAR, as in *Here is something interesting. There comes the difficulty*. (Krzeszowski, 1997)
- GOOD IS UP – BAD IS DOWN, as in *We hit a peak last year, but it's been downhill ever since*. (Lakoff and Johnson, 1980)
- MORE IS UP – LESS IS DOWN, as in *My income rose last year. He is underage*. (Lakoff and Johnson, 1980)
- HAPPY IS UP – SAD IS DOWN, as in *I'm feeling up today. He's really low these days*. (Kövecses, 2002)
- VIRTUE IS UP – DEPRAVITY IS DOWN, as in *She is an upstanding citizen. That was a low-down thing to do*. (Lakoff and Johnson, 1980)
- POWER IS UP – POWERLESS IS DOWN, as in *I'm on top of the situation. He is under my power*. (Lakoff et al., 1991)

3.2. Participants

The study was conducted with 65 German speaking participants. They were recruited in two age groups. The 'young' group included 33 younger adults ($M = 25.5$ years, $SD = 3.7$) with 14 female and 19 male participants. Roughly two third of them held a university entrance qualification, almost a quarter had a secondary school or other school certificates and just about one sixth had a university degree. All but two of the young participants were right-handed. The 'old' group included 32 older adults ($M = 65.5$ years, $SD = 4.2$) with 15 female and 17 male participants. Almost half of the old participants held a university entrance qualification; the other half had a secondary school certificate or other school certificates. All but one of the old participants were right-handed. All participants in both age groups had normal or corrected-to-normal vision and no physical restriction of finger or arm flexibility. Participants received a reward for taking part in the study (8€).

3.3. Procedure and apparatus

The study started with a short introduction to the purpose of the study and an interview about demographic details (age, education, physical complaints). To make the idea of gesture interaction clearer to the participants, they were shortly introduced to 2D touch and 3D free-form gesture interaction. This was done by showing two applications on an Apple iPod Touch 2G that made use of 2D and 3D input facilities (i.e. *Spin the Bottle* and *iBowl live*).

The main study had two parts of which only the second part is of relevance to this paper. The first part was concerned with 2D touch and 3D free-form gestures that could be freely chosen by the participants in response to specific target phrases. The second part was concerned with 2D touch and 3D free-form gestures that were each performed on a given spatial dimension (i.e. CENTRE–PERIPHERY, FRONT–BACK, NEAR–FAR, UP–DOWN). The second part consisted of two blocks of trials – one in which participants performed 2D touch gestures and one in which they performed 3D free-form gestures. Half of the participants started on the block with the 2D touch gestures, the other half started with the 3D free-form gestures. In the 2D touch condition participants were instructed to perform movements with one or more fingers on the surface of the test device. The 2D gestures could range from a simple tap with a fingertip on the surface of the device to complex stroke patterns drawn on the surface sequentially or simultaneously with multiple fingers. In the 3D free-form condition, the participants were asked to freely move the device around in space, including dislocation, tilting and turning of the device.

Both types of gestures were performed with an Apple iPod Touch as a prototypical example for a mobile device that could theoretically recognise 2D touch as well as 3D free-form gestures. The iPod was switched off during the trials to prevent priming participants by any form of graphical display and to prevent reinforcing gestures the device could successfully recognise and give appropriate feedback on.

At the beginning of each block, participants were asked to perform gestures for each of the four image-schematic dimensions (i.e. CENTRE–PERIPHERY, FRONT–BACK, NEAR–FAR, UP–DOWN). This was done to ground the participants in using these dimensions. After this, the main trials followed. In each of these, participants were given a dimension (e.g. UP–DOWN) and a target phrase for an abstract concept (e.g. *unfamiliar*, see below). Unknown to the participants, the dimension and the target phrase together represented a primary metaphor from the list above. Participants were instructed to spontaneously perform any gesture on this spatial dimension that came to their mind and that represented the target phrase. To avoid sequence effects, the target phrases within a gesture block were presented in random order.

The 2D touch gestures were performed holding the device in one hand while performing gestures on the display with the fingers of the other hand. The 3D free-form gestures were performed by freely moving the device in 3D-space, including hand and arm movements (Fig. 3). The experimenter documented the spatial direction of the gestures on an evaluation sheet during the study. As the relevant dimension of movement was clearly stated beforehand (e.g. UP–DOWN), it was easy to determine in which of the two possible directions the gesture was performed (e.g. UP or DOWN). So, for example, the ambiguity of the 2D touch gesture in the left panel of Fig. 3 could be resolved easily. In principle, the gesture is ambiguous, because it could be interpreted as a FRONT gesture with relation to the participant or an UP gesture with relation to the device. But because UP-DOWN was the given dimension, it was clear that the participant reacted within the framework of the device. This interpretation of the gesture could also be checked against the gesture the participant made when he was asked to represent the dimension UP-DOWN as a 2D touch gesture (see last paragraph above). The gestures were also recorded with a commercially available camcorder for later reference.

After performing the gestures, participants were tested for their cognitive speed and indicated their levels of prior experience (see below). A debriefing concluded the session, in which participants could ask questions and offer comments on the study. Each session lasted between 45 and 60 min.

3.4. Target phrases

Table 1 contains the target phrases of each target domain of the primary metaphors included in the study. German target phrases were carefully chosen as not to prime the image-schematic direction. One exception are the target phrases for the metaphor CONSIDERED IS NEAR, because no un-metaphoric way of expressing the target domain could be found in German. The German phrases literally read ‘to draw into consideration’ and ‘to release something out of consideration’, which could prime movements towards (NEAR) or away from (FAR) the participant.

Each participant received only the target phrase of one pole per metaphor (e.g. *freundlich* but not *unfreundlich*) to avoid priming by the opposite member of a pair. Each participant received an equal number of positive and negative target phrases. The phrases were equally distributed across participants. The order of the target phrases for each participant was randomised within blocks.

3.5. Measures of technology experience and cognitive ability

Prior experience with technology was measured on three levels: experience with 2D touch gesture interaction, with 3D free-form gesture interaction, and a general measure of computer experience. Experience with 2D touch gesture interaction involved all kinds of 2D finger-touch interaction on displays of ATM machines, ticket machines, or mobile phones and was operationalised as the maximum number of years any touch device was used. Experience with 3D free-form gesture interaction refers to experience with operating devices by swing or tilt gestures, e.g. the Wii Remote controller or some models of mobile phones. It was operationalised by a binary variable indicating whether participants had experience with 3D gesture interaction or not (coded as 1 or 0, respectively). Computer experience was measured with three items on which users rated their proficiency in using a personal computer and the internet as well as their programming skills. The answers ranged from 1 = ‘marginal’ to 5 = ‘excellent’ proficiency. The scores of these three items were averaged to form an aggregated computer experience score.

Cognitive ability was measured as information processing speed. Processing speed has been proposed to account for other age-related differences in cognitive ability (Salthouse, 1996). It was operationalised via the d2 Test of Attention (Bates and Lemay, 2004; Brickenkamp and Zillmer, 1998), more specifically the TN-E measure indicating the amount of total correctly processed stimuli within a given time.

4. Results

4.1. Validity of primary metaphors

The first two hypotheses state that that the proportion of participants preferring metaphor-congruent gestures is well above

Fig. 3. Example gesture responses. Left panel: 2D touch gesture, target phrase *good* on the dimension UP–DOWN. Middle panel: 3D free-form gesture, target phrase *good* on the dimension NEAR–FAR. Right panel: 3D free-form gesture, target phrase *friendly* on the dimension UP–DOWN.

Table 1
Target phrases used in the study.

Target domain	Target phrases (German)	Target phrases (English translation)
Importance	wichtig, unwichtig	Important, unimportant
Time	Zukunft, Vergangenheit	Future, past
Progress	erneuern, veralten	To renew, to become obsolete
Similarity	ähnlich, unähnlich	Similar, dissimilar
Familiarity	vertraut, fremd	Familiar, strange
Items to be considered	in Betracht ziehen, außer Acht lassen	To consider, to disregard
Valence	gut, schlecht	Good, bad
Quantity	viel, wenig	Much, a little
Happiness	glücklich, traurig	Happy, sad
Virtue	freundlich, unfreundlich	Friendly, unfriendly
Power	mächtig, machtlos	Powerful, powerless

chance level (50%) and that the agreement of gestures with primary metaphors is the same for 2D and 3D gestures. The results of the 2D touch gestures are contained in Table 2, the results of 3D free-form gestures are contained in Table 3. The combined 2D touch + 3D free-form gesture scores are contained in Table 4. The columns show the percentage of answers that were consistent with the metaphor in each group (*young group*, *old group*) and across groups (*overall*). The columns also contain an index of metaphor strength (*str*) that is formed after Cohen's kappa (Cohen, 1960) as a measure of agreement. The *str* index takes into account the chance probability of gestures being congruent with the metaphor (i.e. 50%) and is calculated as

$$str = (\text{observed agreement} - \text{probability of chance agreement})/(1 - \text{probability of chance agreement})$$

A strength value of zero thus indicates chance selection of the gesture's direction and hence a lack of population stereotype, while a strong stereotyped response is reflected by a strength value approaching 1. If the participants disagree with the metaphor, *str* is negative and approaches minus 1. A more fine-grained interpretation of the strength value is offered by Landis and Koch (1977): a negative value of *str* indicates 'poor' agreement, a value below .20 'slight' agreement, below .40 'fair' agreement, below .60 'moderate' agreement, below .80 'substantial' agreement, and above that 'almost perfect' agreement.

Although any *str* value above zero indicates that there were more metaphor-congruent than metaphor-incongruent responses, design guidelines should not be derived from any result with *str* < .60 (80%). This threshold corresponds approximately to the strength values of more traditional population stereotypes (Chan et al., 2003; Hurtienne et al., 2009). Any mappings with *str* < .60 are therefore italicised in the tables below.

The results show that overall agreement with the metaphors is 92% (*str* = .84, Table 4); 90% for two-dimensional touch gestures (*str* = .80, Table 2) and 93% for three-dimensional free-form gestures (*str* = .87, Table 3). Overall, for all metaphors in the combined view (2D + 3D gestures, Table 4) *str* values exceeded the threshold of .60 indicating substantial agreement with the primary metaphors. The strongest metaphors are FAMILIAR IS NEAR, HAPPY IS UP, and IMPORTANT IS CENTRAL, each with a *str* value above .90. The relatively weakest metaphors are PROGRESS IS IN FRONT and CONSIDERED IS NEAR, each with an overall *str* value below .80 (Table 4, overall column). In fact, across all results there is only one metaphor that does not reach the threshold of 80% (*str* = .60) agreement, although its value is still beyond chance (i.e. 78%, *str* = .56). This confirms the first hypothesis that the proportion of participants preferring metaphor-congruent gestures is well above chance level (50%, *str* = .00).

None of the overall differences in strength values between 2D touch (Table 2) and 3D-free-form gestures (Table 3) for single metaphors reaches statistical significance (Exact Wilcoxon signed-rank test, two-tailed). This adds credibility to the second hypothesis that agreement of gestures with primary metaphors is not dependent on the type of gestures.

4.2. Differences between old and young participants

According to Hypothesis 3, the proportion of metaphor-congruent gestures should not differ between age groups. Young and old participants showed similar overall agreement for 2D and 3D gestures combined, 93% (*str* = .87) and 90% (*str* = .80), respectively (Table 4). For the combined gestures, none of the differences for single metaphors between the young and the old group were significant, except for the metaphors GOOD IS UP, Mann–Whitney $U = 410.50$, $p < .01$, $r = -.32$, and GOOD IS NEAR, $U = 427.00$, $p < .05$, $r = -.26$.

Differences between old and young participants were not significant for all metaphors in the 2D condition, except for GOOD IS UP, $p < .05$ (Fisher's exact test, Table 2). However, none of the differences between young and old participants reached statistical significance in the 3D gesture condition (Table 3).

Another way of comparing metaphor-agreement scores is at the individual level (Table 5). For each person, the average agreement of gestures with metaphors was computed. The results show that the young and old groups differed on this measure with regard

Table 2
Agreement with primary metaphors for 2D touch gestures.

Target domain	Image schema	Young group		Old Group		Overall	
		%	*str*	%	*str*	%	*str*
Importance	CENTRE–PERIPHERY	97	.94	94	.88	95	.91
Time	FRONT–BACK	91	.82	81	.63	86	.72
Progress	FRONT–BACK	85	.70	94	.88	89	.78
Similarity	NEAR–FAR	91	.81	88	.75	89	.78
Familiarity	NEAR–FAR	97	.93	100	1.00	98	.97
Items to be considered	NEAR–FAR	84	.69	81	.63	83	.66
Valence	NEAR–FAR	94	.88	81	.63	88	.75
Valence	UP–DOWN	100	1.00	81	.63	91	.82
Quantity	UP–DOWN	97	.94	81	.63	89	.78
Happiness	UP–DOWN	94	.88	97	.94	95	.91
Virtue	UP–DOWN	94	.88	*78*	*.56*	86	.72
Power	UP–DOWN	88	.75	91	.81	89	.78
Mean		93	.85	87	.75	90	.80

Note: Mappings with *str* < .60 are italicised.

Table 3
Agreement with primary metaphors for 3D free-form gestures.

Target domain	Image schema	Young group		Old group		Overall	
		%	*str*	%	*str*	%	*str*
Importance	CENTRE–PERIPHERY	91	.82	100	1.00	95	.91
Time	FRONT–BACK	91	.82	100	1.00	95	.91
Progress	FRONT–BACK	88	.76	81	.63	85	.69
Similarity	NEAR–FAR	88	.76	94	.87	91	.81
Familiarity	NEAR–FAR	94	.88	97	.94	95	.91
Items to be considered	NEAR–FAR	94	.88	84	.69	89	.78
Valence	NEAR–FAR	100	1.00	91	.81	95	.91
Valence	UP–DOWN	97	.94	84	.69	91	.82
Quantity	UP–DOWN	94	.88	94	.88	94	.88
Happiness	UP–DOWN	100	1.00	97	.94	98	.97
Virtue	UP–DOWN	97	.94	94	.88	95	.91
Power	UP–DOWN	97	.94	97	.94	97	.94
Mean		94	.89	93	.86	93	.87

Table 4
Agreement with primary metaphors for 2D touch and 3D free-form gestures combined.

Target domain	Image schema	Young group		Old group		Overall	
		%	*str*	%	*str*	%	*str*
Importance	CENTRE–PERIPHERY	94	.88	97	.94	95	.91
Time	FRONT–BACK	91	.82	91	.81	91	.82
Progress	FRONT–BACK	86	.73	88	.75	87	.74
Similarity	NEAR–FAR	89	.79	91	.81	90	.80
Familiarity	NEAR–FAR	95	.91	98	.97	97	.94
Items to be considered	NEAR–FAR	89	.79	83	.66	86	.72
Valence	NEAR–FAR	97	.94	86	.72	92	.83
Valence	UP–DOWN	98	.97	83	.66	91	.82
Quantity	UP–DOWN	95	.91	88	.75	92	.83
Happiness	UP–DOWN	97	.94	97	.94	97	.94
Virtue	UP–DOWN	95	.91	86	.72	91	.82
Power	UP–DOWN	92	.85	94	.88	93	.86
Mean		93	.87	90	.80	92	.84

to 2D gestures, Mann–Whitney $U = 378.50$, $p < .05$, $r = -.25$, but no significant differences were found for 3D gestures and for a combined measure of 2D and 3D gestures.

Reviewing these results, the overall conclusion seems to be that in general the proportions of metaphor-congruent gestures are the same for young and old users, although there were differences for 2D touch gestures on the individual level and for metaphors in the target domain of valence on the group level. Thus, the third hypothesis could only be partly confirmed.

Table 5
Individual differences between the younger and older user groups.

Variable	Young group		Old group		Difference
	M	SD	*M*	SD	
Touch experience (years)	7.39	3.71	6.16	4.11	*
Gesture experience (%)	64		0		***
Computer experience 1–5	3.33	.85	2.35	.83	***
Cognitive ability d2	489.64	69.72	286.00	66.56	***
Agreement 2D (%)	93	11	87	12	*
Agreement 3D (%)	94	14	93	13	n.s.
Agreement 2D + 3D (%)	93	10	90	10	n.s.

Notes: *M*, mean; SD, standard deviation. Significance levels: $^{*}p < .05$, $^{***}p < .001$, n.s., not significant.

4.3. Correlation of metaphor agreement with age, prior knowledge, and cognitive ability

The fourth hypothesis states that although both age groups differ in their prior experience with technology and their cognitive abilities, the amount of individual agreement with metaphors should show only low correlations with prior experience with technology or cognitive ability. As a manipulation check, the difference between the two samples with regard to prior experience and cognitive ability was determined (Table 5). As predicted, the age groups differed in their prior experience with touch interaction, Mann–Whitney $U = 367.00$, $p < .05$, $r = -.26$; gesture interaction, $U = 192.00$, $p < .001$, $r = -.68$; and computer experience, $U = 205.00$, $p < .001$, $r = -.53$. Thus, across all three measures, the technology experience of older adults was lower than that of younger adults. Cognitive ability was also markedly different between age groups, $U = 21.50$, $p < .001$, $r = -.82$. Older participants had a slower cognitive processing speed than younger participants. This confirms the first part of the fourth hypothesis.

Correlation analyses were conducted to reveal the relation between age, prior knowledge, cognitive ability, and agreement with metaphors (Table 6). The results show the expected negative correlations of age with gesture experience, computer experience, and cognitive ability. The correlation of age with touch experience is not significant. The correlation of age with all metaphor-agreement scores is not significant. This result can be regarded as further support for Hypothesis 3 (no age effects on metaphor agreement).

The correlations of cognitive ability with metaphor-agreement scores are generally low and not statistically significant. The correlations of prior experience variables (touch, gesture, computer) with metaphor-agreement scores are generally low. However, there are small significant correlations of gesture experience and computer experience with metaphor agreement of 2D gestures and of computer experience with the combined 2D + 3D gesture agreement scores. Note that the absolute correlations of the experience variables with age and cognitive ability are higher than their correlations with metaphor-agreement scores.

Given the large correlations of the experience variables with cognitive ability, additional partial correlations were computed (Kendall, 1942) to exclude the common effect of cognitive ability. This reduced the correlation of gesture experience with metaphor agreement of 2D gestures from *tau* = .24 to *tau* = .17; the correlation of computer experience with metaphor agreement of 2D gestures from *tau* = .22 to *tau* = .14; and the correlation of computer experience with overall metaphor agreement from *tau* = .20 to *tau* = .16.

In conclusion, it can be said that the results support Hypothesis 4. Both age groups differ in their prior experience with technology and their cognitive abilities, but these variables show only low correlations with the amount of individual agreement with primary metaphors.

5. Discussion

The purpose of this study was to investigate the validity of primary metaphor theory for deriving physical gestures for manipulating abstract content in a mobile device. A specific focus was laid on the predictions of primary metaphor theory for inclusive design. This section discusses the outcomes of the study and its implications for design. As this is the first study looking into primary metaphors for gesture interaction in inclusive design, emphasis is laid on pointing out future research opportunities.

5.1. Implications for the validity of the theoretical approach for inclusive design

The results show that all four hypotheses could be confirmed or partly confirmed by the data. First, primary metaphors appear to be valid for the design of gesture interaction. The participants appeared to use primary metaphors when performing gestures to convey specific abstract concepts. The proportions of gestures that are metaphor-congruent are above chance level for all abstract target domains. In almost all cases, they also exceeded the threshold of *str* = .60 (80%), showing more than substantial agreement with the predictions of primary metaphor theory.

Second, the data showed that the participants made the same amount of metaphor-congruent gestures when performing 2D touch and 3D free-form gestures. This shows that primary metaphors are valid across different styles of interaction. These results add to a growing body of evidence for the validity and applicability of primary metaphor theory that was investigated in the contexts of graphical user interface design (Hurtienne, 2009; Hurtienne and Blessing, 2007; and Lund, 2003), tangible interaction design (Hurtienne et al., 2009) and full-body interaction design (Antle et al., 2009; Bakker et al., 2009).

Third, the proportion of metaphor-congruent gestures did not differ between age groups for almost all abstract target domains. This is a major advantage for inclusive design, because so far mainly differences between young and old users were documented – in product interaction performance (Blackler et al., 2009; Fisk et al., 2009; Lewis et al., 2008) and also in gesture interaction (Stößel and Blessing, 2010). The current findings indicate that using gestures informed by primary metaphors can be a way of designing inclusive gesture-based user interfaces, for older and younger user groups alike.

Fourth, the correlation analyses showed that agreement of gestures with primary metaphors is not correlated with age. Although both age groups differed with respect to their prior experience with touch screens, gesture interactions, and, more general, computers, correlations of prior technology experience with the proportion of using metaphor-congruent gestures remained rather low. This shows that primary metaphors are suitable to derive design patterns that are independent of the prior technology experience or even the technology generation of users (cf. Docampo Rama, 2001). Furthermore, cognitive ability correlated low and not significantly with the proportion of metaphor-congruent gestures, so that we can assume that primary metaphors also work for people with differing levels of cognitive ability.

Further research needs to empirically establish the superiority of the primary metaphor approach over other approaches used for deriving physical-to-abstract mappings. One common approach to designing inclusive technology is to look at the prior experience of the target users and mimic design patterns from devices that are familiar to these users (Docampo Rama, 2001). As these design patterns would differ for different technology generations, the question remains how this approach compares against the primary metaphor approach when it comes to inclusive design (our third and fourth hypothesis). In further studies it would be desirable not only to collect personal preference data but also data with real user interfaces that are instantiating the respective design patterns in their designs.

As the aim of the present study was to test the theoretical predictions of primary metaphor theory, a hypothesis-testing top-down approach of conducting the research was chosen over an explorative bottom-up strategy. A bottom-up approach to study gestures would leave the users complete freedom to perform their gestures. Analysing the data in terms of image-schematic dimensions would be more challenging, however, because the same gesture might be classified into different image-schematic dimensions (e.g. NEAR–FAR and CENTRE–PERIPHERY) or no image-schematic dimensions at all (e.g. in the case of symbolic gestures, such as alphanumeric symbols or smiley faces). The advantage of such an exploratory approach would be to detect entirely new mappings or primary metaphors that have not been documented before. Whether these would then be universally applicable to user groups

Table 6
Results of correlation analyses (Kendall's *tau*).

	Age	Touch experience	Gesture experience	Computer experience	Cognitive ability	Agreement 2D	Agreement 3D
Touch experience (years)	−.15						
Gesture experience (%)	−.53***	.26*					
Computer experience (1–5)	−.41***	.39***	.32***				
Cognitive ability (d2 score)	−.49***	.17	.38***	.42***			
Agreement 2D (%)	−.08	−.03	.24*	.22*	.18		
Agreement 3D (%)	−.03	.13	.09	.09	.12	.29**	
Agreement 2D + 3D (%)	−.08	.02	.22	.20*	.18	.83***	.61***

* Significance level $p < .05$,
** Significance level $p < .01$,
*** Significance level $p < .001$.

with different prior experience or different levels of cognitive ability (our fourth hypothesis) would remain to be tested. For examples of bottom-up analyses using image-schematic dimensions see Bakker et al. (2009), for bottom-up analyses of user-generated gestures without image-schematic dimensions see Frisch et al. (2009), Mauney et al. (2010), Stößel and Blessing (2010), or Wobbrock et al. (2009).

5.2. Implications for design

All of the primary metaphors investigated in this study lend themselves to be recommended as stereotypical mappings. Most gestures exceeded the threshold of $str = .60$ of being congruent with primary metaphors and can be suggested as guidelines for physical-to-abstract mappings in design. More specifically, this means to employ gestures on the dimension CENTRE–PERIPHERY to convey the abstract concept of importance; to use the dimension FRONT–BACK to convey the abstract concepts of time and progress; to use the dimension NEAR–FAR to convey the abstract concepts of similarity, familiarity, valence, and 'items to be considered'; and to use the dimension UP–DOWN to convey the abstract concepts of valence, quantity, happiness, virtue, and power. These abstract target domains are relevant in complex scenarios where gestures are sought after, for example for social networking applications (e.g. Aras and Huber, 2009), augmenting text messages with the expressiveness of comics (Setlur et al., 2010), document interaction (Liao et al., 2010), diagram editing (Frisch et al., 2009), or tagging of maps (Robinson et al., 2008). As the positive evidence for primary metaphors is accruing for different interaction styles, this growing body of research seems to suggest that primary metaphors can be directly derived from the theory. Designers can either look them up in databases that document these mappings (e.g. ISCAT, Hurtienne et al., 2008) or derive them from their own linguistic analyses (cf. Hurtienne et al., 2009). Both strategies will be faster than a strategy requiring designers to run their own studies to ascertain stereotypical mappings in the target user population (e.g. Antle et al., 2009; Bakker et al., 2009). This study has shown that the results can be valid for heterogeneous user groups – whether they have different backgrounds in experience with technology or have different cognitive abilities.

While this study focussed on a single metaphor and a single gesture at a time, it will be useful to further research the combination of gestures. Primary metaphors could be redundantly combined within one gesture to make for a stronger gesture. For example, when conveying positive valence, the primary metaphors GOOD IS UP and GOOD IS NEAR could be combined in a gesture that requires the user to move the arm upwards and nearer to the body. In addition, it will be interesting to investigate how conflicting predictions of primary metaphors might be resolved, For example, to convey 'a growing sense of frustration' to other members in a social network or in a multi-user game, the metaphors MORE IS UP and HAPPY IS UP make contradicting prescriptions. Previous evidence suggests that it depends on the task which of the conflicting metaphors will be more appropriate (Schubert, 2005; Hurtienne, 2009). For example, when the task is about quantifying the level of frustration, then an upwards gesture should be used, and when the task is about expressing the quality of the emotion, a downwards gesture is more appropriate (e.g. thumbs-down).

6. Conclusion

This research contributes to a growing number of studies applying primary metaphor theory to interaction design. The specific focus here was to investigate the promises of the theory for inclusive design, in particular with regard to the users' varying levels of cognitive ability and prior experience with technology. Primary metaphors were tested in the context of 2D touch and 3D free-form gestures for mobile devices. Summarising the results the following can be concluded: First, relying on primary metaphor and image schema theory may be a valuable strategy for user interface design. This study has shown that the approach is valid for multitouch and free-form gesture interaction. Second, the presented approach seems particularly suited in the quest for inclusive design. The results show almost no age-related differences in metaphor agreement between a young and an old age group, although the two groups differed significantly in prior experience and cognitive ability. Third, on all investigated physical-to-abstract mappings we could show substantial or near perfect agreement with the predictions of the theory across all participants, suggesting that the reported mappings rooted in cognitive linguistics research could indeed serve as design guidelines for gesture-based interfaces. This is the first time that primary metaphor theory has been explored for designing 2D touch and 3D free-form gestures with the possible application areas of mobile devices. We believe, however, that this approach is transferable to different application domains and interaction paradigms. This is also the first time that primary metaphor theory has been explicitly applied to questions of inclusive design relating the results to the prior experience and cognitive ability of the users. Further research needs to look at the usefulness of primary metaphors in more complex user interface designs, also analysing the performance of users and comparing the approach with other approaches in inclusive design.

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