Comparing Pictorial and Tangible Notations of Force Image Schemas

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ABSTRACT

Force image schemas (FIS) are cognitive representations of our naïve understanding of physical force dynamic events in the world. Designers have been struggling to apply FIS in their design processes, because their deliberate use has been made difficult by applying too abstract notations. In this paper we try to advance FIS as a possible theoretical framework for tangible design and present new pictorial and tangible notations of FIS that aim to be more directly applicable. The new notations were tested by asking non-experts to (1) match pictorial and tangible FIS representations to force image schema names and (2) to develop design ideas based on these pictorial or tangible representations. While the group working with the pictorial notations was more correct in assigning FIS names to FIS representations, design ideas tended to be more tangible and interactive in the group working with the tangible FIS notations.

Author Keywords

Tangible interaction design; force image schemas; design guidelines; image schematic metaphors; haptic interaction.

ACM Classification Keywords

H.5.2. Information interfaces and presentation (e.g., HCI): User Interfaces – Theory and methods.

INTRODUCTION

Many studies of tangible interaction design use image schemas and their metaphorical extensions as tools for inspiration. Image schemas as introduced by Johnson [13] are abstract representations of recurring dynamic patterns of bodily interactions that structure the way we understand the world. Image schemas exist beneath conscious awareness what makes them interesting for designing intuitive interactions [7, 9]. They integrate information from multiple modalities and can be represented visually, haptically, kinesthetically or acoustically. Depending on the author, about 30 to 40 of such image schemas are distinguished [5, 13]. Hurtienne [7] organizes these into seven groups: basic image schemas like SUBSTANCE and OBJECT; space image schemas like CENTER-PERIPHERY and UP-DOWN; containment image schemas like FULL-EMPTY and CONTAINER; multiplicity image schemas like SPLITTING and COLLECTION; process image schemas like ITERATION and CYCLE; attribute image schemas like BIG-SMALL and HEAVY-LIGHT; and, finally, force image schemas, like ATTRACTION and BLOCKAGE.

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The actual strength of image schemas lies in their metaphorical extensions to structure abstract concepts. Examples of such metaphorical extensions include: ACTIVITIES ARE CONTAINERS, as in: *she used to delight in washing clothes;* UNPROBLEMATIC IS SMOOTH – PROBLEMATIC IS ROUGH, as in: *Top management faces a potentially rough ride. Don't interfere with the smooth running of our love life;* HAPPY IS UP – SAD IS DOWN, as in: *I'm feeling up. He is really down these days.*

Tangible interaction design can use image schemas as topological, spatial and object attributes to inspire new physical-to-abstract mappings. Previous research, for example, has shown that metaphorical mappings of object attributes to a large extent follow image-schematic metaphors proposed from linguistic analysis [12, 15] and can also be found in the spontaneous use of tangible artifacts and full body interaction [1, 2, 3]. Combined with the linguistic analysis of user's utterances image-schematic metaphors can also inspire the design process of full-scaled graphical and tangible user interfaces [7, 9, 11, 14] with original and novel designs that at the same time are intuitive to use.

In this paper, the focus is on force image schemas (FIS) – cognitive representations of our naïve understanding of physical force dynamic events in the world. FIS are promising for tangible interaction design – whether used in their physical instantiations or as instantiations of their metaphorical extensions. From previous studies we know that FIS can be a challenge to apply because of their too abstract notations. Hence, we devised new sets of image schema representations – one pictorial, one tangible – and tested these for their effectiveness in analysis and design.

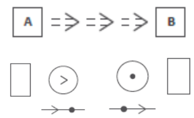
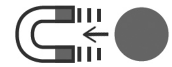
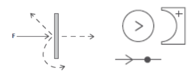
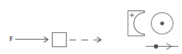
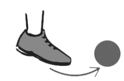
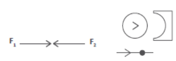
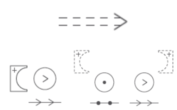
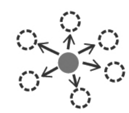
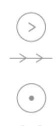
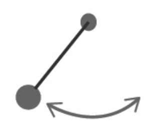
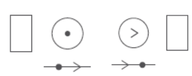
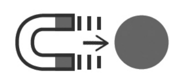
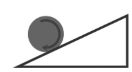
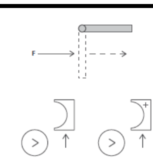
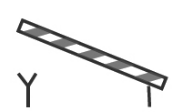
FIS*	Definition	Original notation [13, 19]	UI Example (Physical or Abstract)	New pictoral notation
AT	A (passive) object exerts a force on another object, to pull it toward itself, mostly acting from a distance.		If the seatbelt is not fastened in the car, then a beeping sound is activated to alert the driver.	
BA	Forces and/or weights counteract/ balance off one another. Meta–phorically, there is equilibrium, not too much and not not enough.		Countersteering when slowly riding a bicycle.	
BL	A force/movement is stopped or redirected by an obstacle.		The car driver pulls on the handbrake to prevent inadvertent rolling.	
CP	An external force causes some passive entity to move.		The car driver steps on the accelerator and the car accelerates.	
CF	The active meeting of opposing forces that are equally strong. Both forces collide; there is no further movement.		The plane pilot struggles against the autopilot about changing height. The plane neither descends nor ascends.	
DI	Forces that meet and produce a change in direction or force vectors (at least one).		A ringing phone diverges the user from doing her actual task.	
EN	Having the power to perform some act or a potential force (vector) and the absence of BL, RS, CF or CP		When the car is taking a bend, the cornering light actively lights into the bend where the driver needs to look. (active EN)	
MO	The tendency of an object to maintain the actual state of motion (or rest) if there is no influence of another agent.		The progress indicator of an mp3-player is moving as long as the song is playing or until stopped.	
RP	A (passive) object exerts a force on another object, to repel it, mostly acting from a distance.		A sudden loud noise from the anti-theft device is repelling the thieve.	
RS	A force that tends to oppose or retard the motion of another entity.		A heavily embellished font slows reading.	
RR	The removal of a barrier to the action of a force, or absence of a barrier that was potentially present.		The car driver releases the handbrake to move off.	
SM	A resting entity starts moving without any forces acting on it.		The backing up of data is taking place automatically.	

Table 1: Force image schema definitions, notations and examples. The last column contains the new FIS icons.
***ATTRACTION (AT), BALANCE (BA), BLOCKAGE (BL), COMPULSION (CP), COUNTERFORCE (CF), DIVERSION (DI), ENABLEMENT (EN), MOMENTUM (MO), REPULSION (RP), RESISTANCE (RS), RESTRAINT REMOVAL (RR), SELF MOTION (SM)**

FORCE IMAGE SCHEMAS

What are Force Image Schemas?

The idea of a special group of force image schemas originates in cognitive linguistics [13, 19]. Force image schemas are cognitive representations of our naïve understanding of physical force dynamic events in the world. Accordingly, language specifies only selected aspects of a force dynamic scenario and heavily abstracts from other dimensions of experience: "[Force dynamics] presents an extremely simple representation of causality, one that marks few distinctions and lumps together ranges of diversity. This representation abstracts away, for example, from particularities of rate, scope of involvement, manner of spread, and the like." ([19], p. 92). More concretely, most force interactions that are encoded in language can be reduced to the following properties ([19] p. 97): two forces are involved – not one, and not three or more; the two forces are opposing each other – not acting in concert in the same direction; the two forces are opposing each other 180° head on – not coming at each other at some other angle; a force is acting along a straight line – not along a curved line, not concentrically outward or inward; there is a constant force tendency in the Agonist (the focal force tendency) – not one that varies; this force tendency has two values: toward either action or rest – not one of multiple or continuous value; the resultant state in the Antagonist (the opposing force entity) is also two-valued: either action or rest – not one of multiple or continuous value.

Talmy points out that these characteristics form the conceptual naïve physics of force dynamics that is reflected in language, because the same pattern can be seen across different unrelated languages. He delivers a first set of force image schemas, i.e. ATTRACTION (AT), BLOCKAGE (BL), COMPULSION (CP), ENABLEMENT (EN), RESISTANCE (RS), and RESTRAINT REMOVAL (RR) that all follow the above characteristics [19]. Other force image schemas, albeit with a looser understanding regarding their characteristics were introduced by Johnson [13]: COUNTERFORCE (CF), BALANCE (BA), and DIVERSION (DI). On the basis of strong psychological evidence [4, 17], we added MOMENTUM (MO) and SELF-MOTION (SM) to the group of force image schemas. An overview of the force image schemas is given in Table 1 along with definitions and user interface examples.

As with other image schemas, in tangible interaction design, force image schemas can be used physically and metaphorically. When applying FIS to design, it is useful to differentiate the Agonist from the Antagonist in the force interaction. Several possibilities exist: (1) The user is the Agonist, the technology is the Antagonist. (2) The technology is the Agonist, the user is the Antagonist. (3) Users are Agonists and Antagonists, where the technology has a mediating or representing role. (4) Other agents are Agonists and Antagonist and the user interface is a representation of their force dynamic processes.

Force image schemas can always be useful design aids when representing or mediating real physical forces through the user interface (e.g. control rooms in factories and chemical plants). The type of instantiation may differ: from providing physical force feedback to a visualization of movement trajectories.

FIS can also be used in metaphors to express abstract information. The most common application areas include the representation and manipulation of causality, e.g. starting, stopping, and letting physical and abstract processes. FIS can be used to express social forces, as in *She pushes us to our limits* (COMPULSION), or *My doctor has forbidden me to drink alcohol* (BLOCKAGE). This can be extended to the modeling of rules and regulations in business processes, processes of negotiation and argumentation, as well as diplomatic or even military conflicts. FIS can also be used to represent metaphoric psychological forces, e.g. emotions, as in *I am moved by this poem* (COMPULSION) and inner-psychic conflicts as in *He is wrestling with his feelings* (COUNTERFORCE).

Although FIS have been used in previous tangible interaction research [1, 11], their use, compared to other image schemas, remains rather limited. The reasons could be that FIS are harder to detect and categorize than other groups of image schemas. Much of this has to do with their dynamic and transient nature. Whether something is UP or DOWN, IN or OUT, BIG or SMALL is obvious and can be easily detected. Whether something is ATTRACTING, RESISTING or BLOCKING something else may be subtler to identify. Space, attribute and containment image schemas are often instantiated by static entities. FIS like COMPULSION, MOMENTUM, and DIVERSION, in contrast, are instantiated by the more transient dynamics of two or more interacting forces that may be more difficult to detect in the fleeting moment. Furthermore, FIS can be instantiated in both physical (e.g. blocking the movement of a lever) and abstract ways (e.g. blocking an un-authorized user from accessing a website) – the variety of instantiations makes it difficult to detect the underlying pattern.

To sum up, although the potential of FIS for TUI is great, there seem to be some hurdles to their application in interaction design that have to do with teaching and identifying FIS in action. We propose that looking at FIS notation systems might eventually provide a solution to bring FIS closer to those designers that are not image-schema experts.

Original FIS notations

Talmy [19] also developed a notational system for the force image schemas he proposed. Its basic elements are shown in Figure 1. In this system, there is always an Agonist and a stronger or weaker Antagonist. Agonists have either an intrinsic tendency toward rest or toward motion. In Talmy's notational system, the Agonist is indicated by a circle and the Antagonist by a concave form. Further, the Agonist's intrinsic force tendency, the resultant of the force interaction, and whether an entity is stronger or weaker than the other is coded in the notation. In the example of the notation of the blockage image schema, for example (see Table 1), the Agonist's tendency is towards action, but it is held back by a stronger Antagonist so that the Agonist is kept in place.

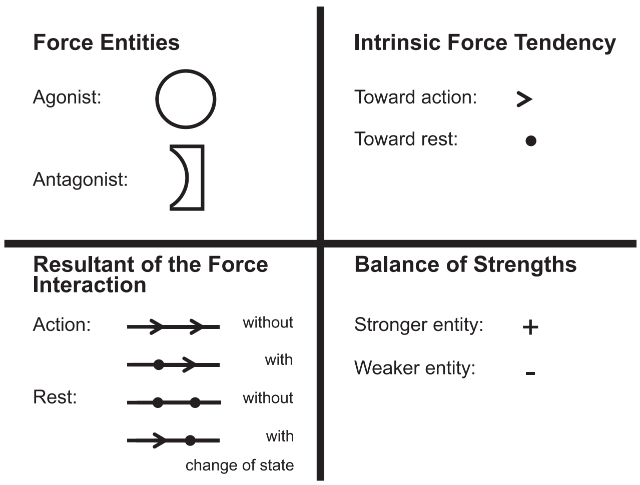


Figure 1. Elements of Talmy's [19] notation of force-dynamic elements.

Johnson's [13] notational system is rather informal and intuitive and depicts the meeting of forces and their resultants as movements on straight paths. Both notations are included in the overview of force image schemas in Table 1.

In a previous study [8], four designers familiar with force image schemas were provided with Johnson's and Talmy's notations and categorized 80 short force-dynamic episodes describing human-technology interactions (e.g. *The driver released the handbrake* as an example of restraint removal) into ten FIS categories (AT/RP, BA, BL, CF, CP, DI, EN, MO, RR, RS). The results show that while 73% of classifications were correct, many category confusions occurred. Confusions were more likely when image schema definitions overlapped. Some FIS differ only in degree of force strength (e.g. the increasing degree of Antagonist strength from RESISTANCE to COUNTERFORCE to BLOCKAGE) or are the precondition or consequence of another image schema (e.g. a BLOCKAGE, RESISTANCE, or COUNTERFORCE is the precondition of RESTRAINT REMOVAL; ENABLEMENT is a direct consequence of RESTRAINT REMOVAL; DIVERSION is a likely consequence of COMPULSION, ATTRACTION/ REPULSION, BLOCKAGE, COUNTERFORCE, and RESISTANCE). From the results of the study a number of suggestions for the training of image schema coders were derived. However, if image schemas are to be used in daily design processes, a specialized FIS training would not be feasible and we would need other ways of teaching.

The previous study has also shown that useful results can already be achieved with an introduction to FIS that lasts as long as 30 minutes. We, however, believed that neither the highly systematic notation of FIS by Talmy nor the informal sketches by Johnson would be of much help in quickly learning the definitions of force image schemas and making them easily applicable in practice. Therefore we devised two new sets of notations, one pictorial, the second tangible, based on force-dynamic prototypes. The aim was to see whether people could easily match the new FIS representations to FIS definitions and whether their design ideas based on these notations differed in any remarkable sense.

NEW FIS NOTATIONS: PICTORIAL AND TANGIBLE

Designing FIS Icons as a New Pictorial FIS Notation

Seventeen image schema experts were asked to create sketches that illustrate the core concept of each FIS. All of the experts professionally worked with image schemas for 0.5-6 years, mainly due to participation in a related research project. The experts were provided with the name of each FIS and a definition. They were allowed to draw as many sketches as they wanted to. Altogether, a total of 301 sketches were collected for eleven force image schemas (AT, BL, RS, CP, DI, BA, CF, EN, RR, MO, SM). Each sketch was decomposed in single elements, which were categorized as active/passive and object types involved. The final step of the analysis consisted of determining the most frequent characteristics of each FIS and creating a final iconic representation out of these elements (see Table 1, last column). For example, a swinging pendulum visualizes the FIS MOMENTUM and a rolling ball being slowed down by a ramp visualizes the FIS RESISTANCE. The icon for the missing FIS REPULSION was added after this study as a direct opposite of ATTRACTION.

In an informal test, five image schema novices were asked to describe the newly developed icons as well as the notations by Johnson [13] and Talmy [19]. Language analysis of the subjects' speech revealed that their language was consistent with the intended image schemas with the newly developed icons, e.g., 'the ramp impedes the balls movement' (RESISTANCE). However, the subjects in almost all cases were not able to understand and describe Johnson's and Talmy's notations.

Designing FIS Dials as a Tangible FIS Notation

The second attempt in developing 'tools' to support understanding and learning of FIS involved creating physical interactive prototypes. Designers should be enabled to grasp force image schemas in the literal sense (cf. [16]) with the idea that a tangible representation is more conducive to conveying force image schemas than a visual representation.

After collecting and exploring a variety of example FIS instantiations in animation, interactive simulation and early interactive physical prototypes we designed a set of twelve FIS prototypes and one neutral reference model. The prototypes were made very similar to each other to enable direct comparisons between different FIS. Each FIS was instantiated as interactions between a user and a physical rotatory dial. The prototypes were kept free of any applied context, to enable focusing on the FIS themselves. Each prototype consists of a neutral front with a rotary dial, a functional backside, and a side panel with some information regarding the FIS (Figures 2 and 3).

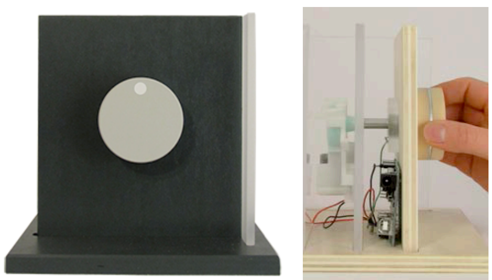


Figure 2. FIS-dial, generic front view (left). Interacting with a FIS-dial (right).

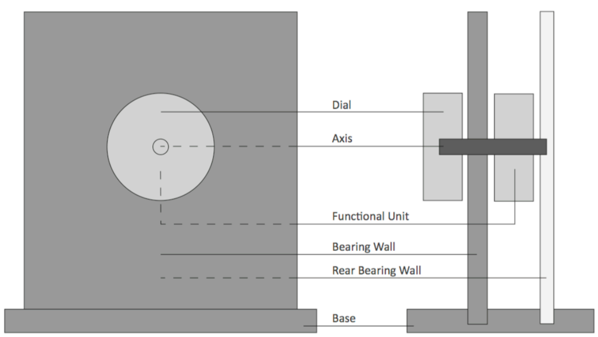


Figure 3. Generic design of FIS-dials.

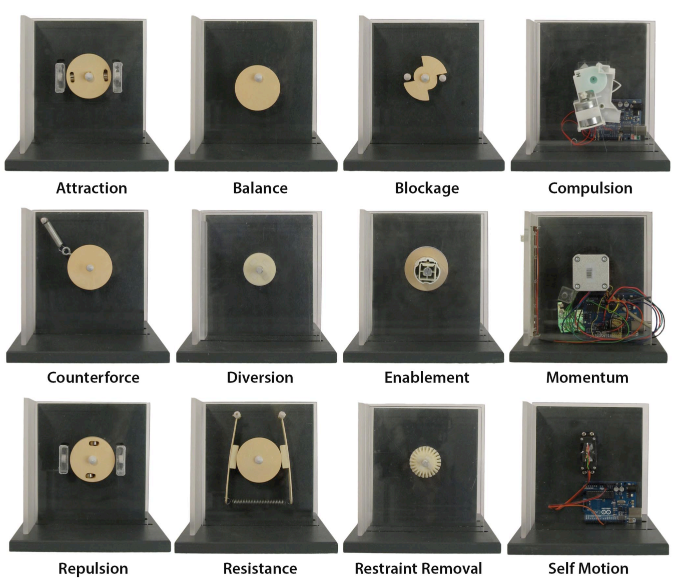


Figure 4: FIS-dials, rear view.

When interacted with, the dial on the front exhibits force image schematic behavior. The backside contains the functional part, implementing an active or passive force feedback mechanism. Passive models give haptic force feedback that is implemented by simple mechanics. Active models contain sensors and actors to perform movements of the dial. They were controlled by Arduino microcontroller boards. Figure 4 gives an overview of the functional backsides of the FIS dials.

ATTRACTION: When the user rotates the dial, a force attracts the dial to certain positions. Implemented with Neodym magnets in the dial and the bearing wall.

BALANCE: After turning the dial it re-assumes its original position. Implemented by a dial that rotates off-center.

BLOCKAGE: When the user rotates the dial, the motion is suddenly stopped. Implemented by wooden sticks hindering the movement of the dial.

COMPULSION: When touching the dial, the dial moves the users' hand. Implemented by sensing contact with a capacitive sensor (aluminium parts in the dial and axle), a simple electric circuit on the Arduino and a geared motor.

COUNTERFORCE: When rotating the dial, the user feels a counteracting force getting gradually stronger until the user can't move the dial further. Implemented with a strong spring attached to the dial and the bearing wall.

DIVERSION: When the user rotates the dial, it moves towards the user on the z-axis. Implemented by two complementary wave shapes. If the wave peaks touch, the dial is in its outer position, if wave peak and trough touch, the dial is back at its normal position.

ENABLEMENT: The existence of a dial that can be rotated already instantiates passive ENABLEMENT. This dial can be sunk into the wall where it cannot be rotated (thereby disabling it). Implemented using a stove knob with a spring mechanism.

MOMENTUM: The dial keeps its state of movement until the user changes it. When the dial does not move and the user rotates it, the dial will continue this rotational movement. When already rotating, the user can stop the dial or change the direction of the rotation. Implemented with a rotation sensor, an Arduino board, and a stepping motor.

REPULSION: When the user rotates the dial, the dial is repelled from certain positions and the user is not able to keep the dial at these positions. Implemented similar to the attraction dial by inversing the magnets' poles.

RESISTANCE: When rotating the dial, the user feels a continuous force that resists his movements. Implemented by using friction between two rubbers and wooden spatulas. A spring connecting the spatulas keeps a constant pressure.

RESTRAINT REMOVAL: This dial can only be moved when the user pulls it out. Implemented by two cogwheel shapes, pushed together by a spring. By pulling the dial the cogwheels are decoupled and the dial can be rotated.

SELF MOTION: This dial spontaneously moves with different speeds and directions. The user cannot influence the movements. Implemented with a modified servomotor and an Arduino board.

COMPARING NOTATIONAL SYSTEMS

We conducted a workshop to evaluate whether the newly developed FIS icons and FIS dials improve the correct identification and distinguishability of FIS by designers freshly introduced to force image schemas (part 1) and to gauge their usefulness in supporting designers to brainstorm design ideas for specific contexts (part 2).

Method

Fifteen students from a course on User-Centered Design at the University of Würzburg (10 male, mean age = 22 years) participated in a workshop as part of their course fulfillment. They received a 30-minute introduction to definitions and examples of the twelve FIS. Then they were randomly assigned to the FIS-dial (n = 7) or FIS-icon group (n=8) that worked in separate rooms. They were told that they were now tested on how good they could match the FIS dials to FIS names, or, in case of the other group, how good they could match FIS icons and FIS names. The dials and icons were displayed on tables and each participant according to his or her route card went to each 'FIS station' in sequence and identified the FIS instantiated by the FIS dials or icons. Multiple answers were allowed. Additionally, participants rated on a 4-point Likert scale how confident they were with their choices (1 = uncertain to 4 = certain). The sequence of FIS icons/dials was randomized and participants had two minutes time for each FIS instantiation.

In the second part of the workshop, the same participants were asked to brainstorm design ideas for all FIS. They were randomly assigned to the application contexts of a driver assistance system (DAS) or a smart phone application (APP). They worked through each FIS in random order and had four minutes time at each FIS. They were required to create sketches and short descriptions of their ideas. The ideas could describe either new or already existing designs.

After they had completed the task (that took about one hour), participants filled out a questionnaire providing demographic data and subjective ratings (6-point Likert scales, 1= strongly disagree to 6 = strongly agree) on how well they understood FIS, whether they were able to apply the FIS in design, whether FIS were helpful in creating design ideas and whether they found FIS important for interaction design.

Results

Image Schema Identification

A trial was counted as 'correct' when participants only chose the correct FIS. It was counted as 'partly correct' when the participants chose the correct FIS among other FIS, and as 'incorrect' when the correct FIS was not chosen at all. An independent samples t-test, $\alpha = 0.05$, revealed that participants in the FIS-icon group ($M = 0.69$, $SD = 0.44$) had more correct matches on average than the FIS-dial group ($M = 0.38$, $SD = 0.44$), $t(178) = 4.74$, $p < 0.001$, Cohen's $d = 0.76$. Unambiguousness of FIS identification was operationalized as the number of answers for each task. Participants in the FIS-icon group ($M = 1.19$, $SD = 0.39$) did choose on average fewer FIS in each matching task than the FIS-dial group ($M = 1.58$, $SD = 0.90$), $t(108.701) = 3.67$, $p < 0.001$, $d = 0.62$. Both groups did not differ in their confidence ratings, $p > 0.1$.

Design Exercise

On average, participants in the FIS-dial group created $M = 20.14$ ($SD = 5.27$) design ideas, whereas the participants in the FIS-icon group created $M = 30.39$ ($SD = 10.64$) ideas. The resulting total of 366 design ideas were rated by an author of this paper according to the criteria correctness (whether the FIS was instantiated correctly, on a scale from 0 to 2), innovation (on a scale from 0 to 3), interactivity (interactive/passive), haptic feedback (haptic/not haptic), visual feedback (visual/not visual) and auditory feedback (auditory/ not auditory).

Figure 5 shows the results for the driver assistance system. Although slight advantages for the FIS-dial group regarding interactivity, haptic feedback and auditory feedback seem to be seen, independent samples t-tests revealed no significant differences for these variables.

Figure 6 shows the results for the smart phone application. Participants that had used the FIS-dials when brainstorming design ideas created designs that were more interactive, $t(137.67) = 2.01$, $p = 0.046$, $d = 0.33$; more haptic, $t(78.84) = 3.45$, $p = 0.01$, $d = 0.66$; more visual, $t(146.256) = 2.50$, $p = 0.01$, $d = 0.36$, but less auditory, $t(161.073) = 3.59$, $p < 0.001$, $d = 0.48$ than the design ideas created from the FIS icons.

Post-Study Questionnaire

The FIS-dial and FIS-icon groups did not significantly differ in their subjective judgment how well they understood FIS and whether they were able to apply FIS in design. Participants in the FIS-icon group judged FIS to be more helpful in creating design ideas, $t(13) = 2.32$, $p = 0.04$, $d = 1.29$, and FIS to be more important for interaction design, $t(13) = 3.29$, $p = 0.006$, $d = 1.82$, Figure 7.

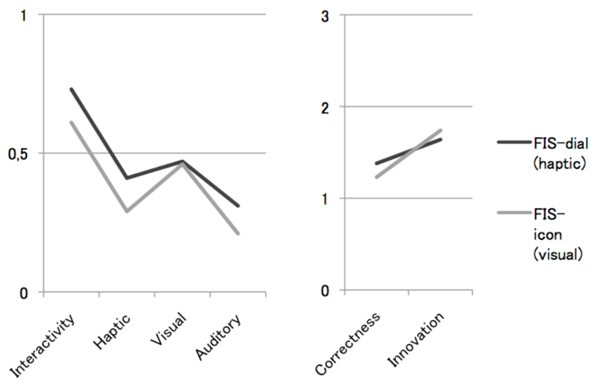


Figure 5. Rating FIS design ideas for driver assistance systems.

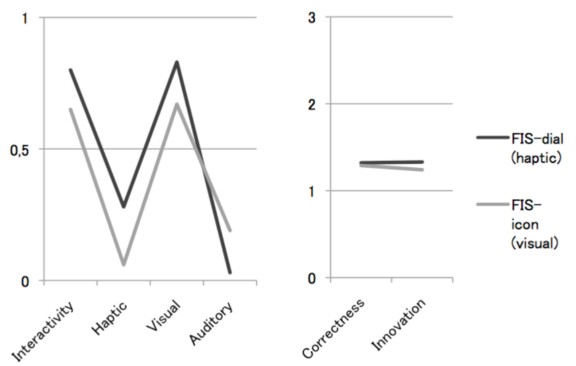


Figure 6. Rating FIS design ideas for the smartphone app.

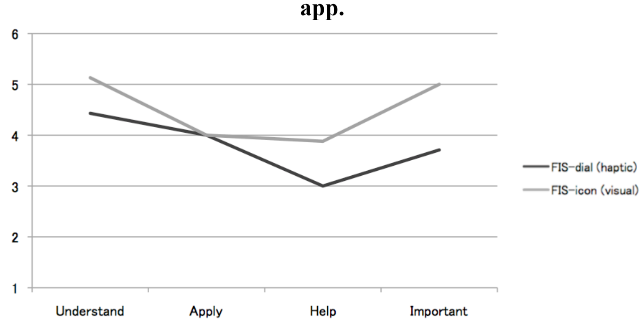


Figure 7. Results of post-study questionnaire.

Discussion

On the one hand, the results seem to demonstrate a clear advantage for the FIS-icon pictorial notation over the FIS-dial tangible notation. Workshop participants were more likely to correctly categorize FIS when using the FIS icons than when using the FIS dials. Thus, equipped with the FIS icons, designers could attain similar FIS recognition rates as the FIS experts in a previous study [8]. Participants in the FIS-icon group also categorized FIS less ambiguously than participants in the FIS-dials group. They also created more ideas in the design exercise. Participants found FIS more helpful and more important for interaction design when they had interacted with FIS icons before. They, however, did not differ in their judgment whether they had understood force image schemas and whether they were able to apply FIS in interaction design.

On the other hand, there seems to be a slight advantage for the FIS-dial tangible notation, when it comes to the quality of design ideas. Participants who used the FIS dials tended to have (in one task even significantly so) more interactive, more haptic and more visual design ideas than participants who used the FIS icons.

Thus, can we draw the seemingly paradox conclusion that, if one wants to achieve a clear understanding of force image schemas, one should use a pictorial notation like the FIS icons rather than a tangible notation like the FIS dials to support learning? And if one likes to inspire tangible interaction (although at the cost of FIS correctness), one should take a tangible representation like the FIS dials? What do these results tell us about the power of tangibles to teach abstract concepts? The answers to these questions cannot be clear-cut as the specific circumstances of this study needs to be taken into account.

First, while the FIS icons were unconstrained in what they visualized, the FIS dials were created with the aim to make the FIS comparable to each other. To the participant they all looked the same (the functional backsides of the prototypes were covered throughout the experiment). It thus seems that focusing attention to the tactile channel at the cost of visual distinctiveness might not be very helpful in learning FIS (cf. [17]). Second, by applying visual constraints to the design of the dials, some FIS, e.g. BALANCE, would not be instantiated in the most suitable way.

Third, while the FIS icons represent a precise snapshot of a continuous action, it is difficult to isolate a precise moment of force feedback in the tangible interaction prototypes. Therefore, some of the FIS dials could represent more than one FIS to the user. For example, the transition between RESISTANCE, COUNTERFORCE, BLOCKAGE and RESTRAINT REMOVAL is gradual and probably needs to be interpreted in relation to an anchor stimulus. Although it was available, the participants rarely consulted the neutral dial prototype. The correct identification of ENABLEMENT and COMPULSION was low, because participants had difficulty discovering that the ENABLEMENT dial had to be pushed to become available and the COMPULSION dial sometimes initiated movement by itself when a participant had a high body voltage and came near the device (creating a possible confusion with SELF MOTION).

Fourth, whereas with the FIS icons a quick look at the pictorial notation was enough to bring the image schema to mind, participants spent more time interacting with the FIS dials. As a result the FIS-dial group had less time left to actually brainstorm design ideas.

Fifth, the FIS dials only communicated one direction of effect: the user as Agonist, the FIS dial as Antagonist, whereas the FIS icons assumed a more neutral stance and showed different actors as Agonists and Antagonists. In the FIS-dials group this one-way focus may have led to fewer design ideas and the feeling of a limited use of FIS as seen in the questionnaire results.

Finally, the participant sample is very small, so that these effects may be due to the specifics of the participants and the situation so that further studies employing larger sample sizes seem to be necessary.

CONCLUSION

This paper introduced force image schemas as a promising group of image schemas for tangible interaction design. Like other image schemas FIS can be used to convey physical and abstract metaphorical meaning via the user interface. In the light of a previous study, it was asked how the analytic understanding of force image schemas by designers who are not image-schema experts might be enhanced. The current systematic notation by Talmy did not seem helpful. Therefore two design aids, a pictorial and a tangible, were derived and tested with image schema novices. It was found that the pictorial representation of force image schemas let to better image schema learning than the tangible representation, while the tangible representation was more likely to produce more tangible and interactive design ideas. The findings open up new areas of thinking about the usefulness of tangible representations for learning abstract concepts. Several problems have been discussed and need to be pursued in further research adding to previous findings about the benefits and drawbacks of using tangibles for learning [10, 16, 18]. In particular, this research has shown that in comparison to pictoral sketches the concreteness of tangibles sometimes may constrain the expression of a pure idea in a way that this idea at the same time becomes less flexible (only one particular stance is presented) and more ambiguous (due to irrelevant affordances, also cf. [6]). There also remains the interesting possibility that tangibles are just too interesting to explore that might stand in the way of solving tasks efficiently. Further research needs to clarify whether these speculations hold true for tangibles under other circumstances.

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