Eliciting Tangible and Gestural User Interactions with and on a Cooking Pan

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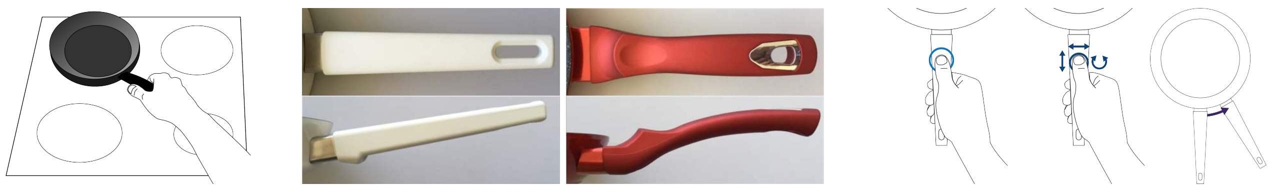

Figure 1: *Left:* schematic illustration of the investigated use case. *Middle:* two pans were use in the study: a white pan with an unstructured, flat pan handle, and a red pan with a structured handle. *Right:* Examples of the elicited interactions: tapping on the pan handle, swiping on the pan handle, and utilizing the pan handle to rotate the pan.

ABSTRACT

Embedding computational capabilities in everyday objects enables novel interaction concepts that are seamlessly integrated in users' everyday tasks. We conducted an elicitation study to investigate how subjects use a pan to control functions related to cooking. The primary focus of the study was to identify whether the elicited proposals tend towards tangible (i.e. moving or rotating the pan) or gestural (i.e. tapping or swiping on the pan handle) interactions. We present an analysis of over 500 interaction proposals from 20 subjects. While priming and used pan handle did not affect the number or type of elicited interactions, we found statistically significant differences for different types of task. While pan interaction is suitable for controlling cook top temperature, subjects have a rejecting attitude towards using a pan to interact with the cooker hood or a digital cookbook. We derive recommendations for when and how to interact with a pan during the cooking process.

CCS CONCEPTS

• **Human-centered computing → User studies**; **Gestural input**; **Empirical studies in interaction design**.

KEYWORDS

Tangible interaction; gestural interaction; elicitation study; Repurposed everyday objects

MuC'20, September 6–9, 2020, Magdeburg, Germany

ACM ISBN 978-1-4503-7540-5/20/09…$15.00
https://doi.org/10.1145/3404983.3405516

ACM Reference Format:
Frank Beruscha, Katharina Mueller, and Thorsten Sohnke. 2020. Eliciting Tangible and Gestural User Interactions with and on a Cooking Pan. In *Mensch und Computer 2020 (MuC'20), September 6–9, 2020, Magdeburg, Germany.* ACM, New York, NY, USA, 10 pages. https://doi.org/10.1145/3404983.3405516

1 INTRODUCTION

Ever since Ishii and Ullmer presented their vision of tangible bits [9], many tangible interfaces have been proposed that repurpose everyday objects as a physical controller substitute for a target system (see section *Related Work*). Referring to Weiser, this is one step to "weave computing technology into the fabric of everyday life" [25]. However, two challenges that were addressed by Corsten et al. [5] still remain: the challenge of ambiguity, i.e. how to differentiate between repurposed object use and regular object use, and the challenge of programming, i.e. how to link the everyday object to the target system.

In this paper, we investigate interactions with a pan to control functions related to cooking on a cook top, as one exemplary setup that might resolve the abovementioned challenges. As an illustrating example, a user can put a pan on the cook top and rotate it to control the temperature of the cooking zone underneath. While the primary purpose of the pan (hold food) remains, controlling the cooking zone temperature constitutes an additional purpose of the pan. The cook top border naturally limits the area in which this additional function of the pan is active. Rotating the pan e.g. on the countertop next to the cook top does not affect cook top temperature. The challenge of ambiguity is fully resolved when the user performs an activating gesture (preferably on or with the pan) to enter temperature control mode. In addition, controlling cook top temperature does only make sense when a pan (or a pot) is put on the cook top. Other everyday objects (e.g. a coffee mug) are excluded as controller substitutes for controlling cook top temperature.

Pan and cook top have a natural functional relation. Similar examples of object and system with natural functional relation are screw and screwdriver, or coffee mug and coffee machine. For example, a coffee mug can be used as controller substitute to adjust the amount of coffee, e.g. by rotating the coffee mug. This additional function of the mug is only active when the mug is placed under the coffee machine. Similary, rotating a screw between the fingers can be used to adjust the screw driver torque, but only when the screw is positioned in front of the screw driver. We assume that the likelihood for real world practical implementation of repurposed everyday objects is higher for such pairs of object and system.

We chose to investigate pan & cook top in detail, as the kitchen appears to be ready for advanced HCI practices (e.g. [15]). The introduction of (depth-) camera-based touch interaction and visual interface projection in the kitchen has been proposed by previous HCI research (e.g. [7, 16, 28]), and is already commercially available today[1]. Cooker hoods offer the possibility to integrate sensing and projection technology over the cook top. In addition, cook tops with connectivity that allow for remote controllability are commercially available already today. Besides that, there seems to exist a user pain with controlling cook tops. For example, Myhill reported that 86% of cook tops in the U.K. have an inappropriate mapping of controls to elements [13].

From the perspective of an interaction designer, the idea of using a pan for rotary input, supported by visual feedback projected on the cook top or the adjacent worktop, is quite obvious, especially given that the pan handle serves as an optimal lever for rotation. At the same time, a pan handle might also serve as touch input surface for user input. We refer to interactions that imply placing and moving (e.g. rotating) the pan as tangible interactions (e.g. [23]). Interactions that utilize the pan handle as (touch) input surface are referred to as gestural interactions accordingly. It is worth mentioning that both tangible and gestural interactions can be seamlessly performed while cooking.

We conducted an elicitation study to find out how subjects use a pan in order to accomplish tasks related to cooking. The main purpose of the study was to identify whether the elicited interactions tend towards one interaction paradigm, i.e. either tangible or gestural interactions. We further investigated whether the instruction that we gave to our subjects (i.e. the order of priming) has an effect on the elicited interactions. Finally, we investigated the effect of different types of pan handles on the elicited interaction set.

In summary, the contributions of our work are

- the provision of a novel interaction concept for a specific cooking application,
- an elicitation study to identify possible and preferred interactions,
- a controlled investigation of the effect of minor changes in the instructions on the elicited interactions.

2 RELATED WORK

Our work is informed by prior research on user elicitation studies, on repurposing everyday objects as controller substitute, and on microgestures.

[1]BSH Home Appliances Group. 2018. The future is bright! The PAI projector paves the way for virtual interaction in the kitchen. Retrieved April 15, 2020 from https://www.bshaccelerator.com/blog/pai-project-interact

2.1 Elicitation Studies for Gesture Interaction

Elicitation studies include end-users in the process of designing an interactive system in a participative approach. This participatory design method where gestures are elicited from end-users was proposed by Wobbrock et al. [26]. Gestures defined by end-users have been found to be preferred by (other) users [12], and are easier to remember [14]. The elicitation method has been adopted from HCI research in various domains, ranging from mobile interactions [19] to bicycling [22] and automotive applications [1].

Liang et al. [10] conducted a user study to elicit surface and motion gestures for 3D manipulation through a mobile device . Their results partly suggest that subjects prefer surface gestures over motion gestures. Motion gestures were preferred in rotation tasks or when the task involved the Z Axis, which is not transferable to our context. We are interested in whether specific tasks are solved e.g. with a rotation interaction. Sharma et al. [21] recently conducted an elicitation study where subjects were asked to perform gestures while grasping various objects. For cylindrical objects, the shape that is closest to that of a pan handle, subjects preferably used their thumb for interaction on the object, e.g. by tapping or swiping.

According to the initially proposed elicitation method [26], subjects are confronted with referents that present the effect of a command, and are asked to provide a suitable gesture command that would result in the given referent. Recent research has differed from this approach, and confronted subjects with tasks [19] or directly with commands [1] instead of referents.

2.2 Repurposing everyday objects for user input

Previous research has built on affordances of everyday objects to serve as controller substitute for a target system. In one of the first projects, Henderson & Feiner [8] propose an interaction technique for augmented reality applications, where unused affordances of objects in the surrounding provide tactile guidance for users . Cheng et al. [4] propose to place markers on everyday objects to make them available as input controls. Corsten et al. [5] and Funk et al. [6] present marker free approaches to repurpose everyday objects. All three provide a programming process to assist users in pairing physical objects to digital target systems.

Pohl and Rohs [18] conduct a user study to identify which objects users repurpose as external controller for smartphone applications. While a couple of everyday objects were available in the surrounding of the smartphone, users hesitated to utilize them as controller substitute. The authors assume that is due to legacy bias and general unfamiliarity with this kind of tangible interaction. It's worth mentioning that all research projects present circular objects as substitute for rotary controls, e.g. coffee mug in [18] and [5], or bottle in [4] and [6].

2.3 Microgestures

Microgestures are subtle and rapid gestures that can be performed with a single hand while being (manually) engaged in a primary task [2]. Few prior work has focused on grasping microgestures, i.e. microgestures that are performed with busy hands. Pioneering work by Wolf et al. [27] provided a taxonomy and initial design guidelines for grasping microgestures, especially driven by ergonomic opportunities. The extensive elicitation study on grasping microgestures conducted by Sharma et al. [21] extended this approach to versatile grasp types and object sizes.

Also related to our work are the previously mentioned investigations of grasping microgestures on self-sustained objects, e.g. cycle handle [22] or steering wheel [1]. In the latter, tapping or swiping gestures with the thumb are among the most frequently proposed gestures, which is in line with the results reported by Sharma et al. [21]. Self-sustained systems however inherently only allow for gestural interactions.

3 METHOD

We conducted an elicitation study to investigate how subjects perform given tasks with a pan.

3.1 Participants

20 subjects (16 female, 4 male) aging from 20 to 58 (mean 40.7) participated in our study. The majority (18) was right handed (0 left handed, 2 ambidextrous according to their own statement). We recruited subjects with non-technical working background, as we assumed that they are less likely to be concerned about technical detectability of the elicited gestures. There were no prerequisites for participation related to cooking experience, as we consider it as some sort of obviously available skill to know how to cook with a pan. We even felt that too much specific domain knowledge (or "chef tips") might finally be counterproductive for the everyday usage scenario. All subjects gave their written informed consent prior to participation.

3.2 Apparatus and setup

The study took place in the Smart Life Lab at Bosch Research Campus Renningen, which resembles a residential environment with customizable living areas. Participants performed the tasks on a cook top in the kitchen area of the lab. Both the cook top and the cooker hood above the cook top are functional but were not activated during the study.

We used two different pans: a white pan with a flat pan handle (also referred to as non-structured pan), and a red pan with a pan handle that offered graspable landmarks suitable for touch interaction (also referred to as structured pan, see Figure 1 *middle*). When procuring the pans, our impression was that most pan handles have some kind of graspable landmarks, presumably for ergonomic reasons, and that pans with plain pan handles are rather rare.

Following the procedure originally proposed by Wobbrock et al. [26], we did not attempt to automatically sense input. Two cameras were used to record the cook top from above and from the side. Subjects' faces were not visible in the camera.

To reduce legacy bias, we used priming [12] by showing subjects videos of potential interactions that are possible with the pan. In the priming video for tangible interaction, an actor performed different interactions with the pan like rotating, moving, lifting or tilting the pan, and explained that the system is capable of recognizing these movements. In the priming video for gestural interaction, the actor performed interactions like grasping the pan handle, lifting fingers, touching the pan handle on various positions, and swiping over the pan handle. The order of presentation of the priming videos was varied between subjects. A third pan with a black pan handle that differed from the red and white pan was used in the priming videos.

Table 1: Tasks in the elicitation study (the code denotes task category and order of appearance of the task, e.g. TE = Temperature setting, 01 = first task).

TE Temperature setting (primary tasks)	
TE01	turn on top left cooking zone
TE02	set temperature to max. value (10)
TE03	decrease temperature from 10 to 3
TE04	increase temperature by one step
TE05	increase temperature from 4 to 9
TE06	decrease temperature by one step
TE16	turn off top left cooking zone
TI Timer functions (secondary tasks)	
TI07	set timer to 20:30
TI08	start timer
TI09	stop timer
HO Cooker hood functions (peripheral tasks)	
HO10	turn on cooker hood
HO11	increase fan speed (from 1 to 3)
HO12	turn on light in the cooker hood
CB Digital cookbook (peripheral tasks)	
CB13	select recipe from list
CB14	go to next step in recipe
CB15	go to previous step in recipe

3.3 Tasks and procedure

We intentionally did not confront subjects with referents but rather asked them to perform typical tasks related to kitchen work with a cook top (see Table 1). The tasks can be categorized in primary (related to temperature setting), secondary (related to timer functions) and peripheral tasks (related to cooker hood settings and interacting with a digital cookbook). While primary and secondary tasks address functions that practically all cook tops offer today, peripheral tasks are related to systems in the periphery of a cook top. The task set comprised discrete (e.g. turn on), binary (e.g. next/previous), and continuous (e.g. temperature selection) tasks, as well as a mixture of these types.

We did not randomize tasks for two reasons. First, we intentionally decided to confront subjects with temperature setting tasks first, as we assumed that these tasks were somewhat easier to accomplish. And second, because the task order for temperature setting stated in Table 1 simulates a realistic task order that can typically occur during real cooking. All subjects performed the tasks in the same order, according to the enumeration in Table 1. The pan was empty at the beginning, and filled with a pack of lentils (800g) after completion of the first task.

3.4 Experimental Design

A between-subject design was chosen for the study. The independent variables were *order of priming* (two levels: gestural/tangible,

tangible/gestural) and *pan handle* (two levels: red (structured), white (non-structured)). Hence, subjects were distributed in 4 groups of 5 participants.

We utilized production [12], continuously engaging subjects to produce multiple interaction proposals for each task while thinking aloud. Comparable to [26], subjects were asked to evaluate goodness and ease of each interaction proposal on 7-point Likert scales.

4 RESULTS

Besides proving an interaction concept proposal, the focus of the analysis is to identify possible effects of priming or pan handle on the elicited interactions.

4.1 Number of produced interactions

We analyzed approx. 700 minutes of video recording and collected a total of 544 pan interaction proposals from the 20 subjects. In 74 cases, subjects did not come up with pan interaction proposals, but rather expected automatic behavior without explicit interaction (e.g. cooker hood should turn on automatically when the cook top is turned on), or considered alternative interactions as superior (e.g. speech interaction, mid-air gestures or conventional controls).

The number of elicited interactions varied substantially between subjects (from 11 to 40) and between tasks (from 15 to 60). Subjects using the red pan produced more proposals (292 in total) than subjects using the white pan (252). Similarly, subjects that were primed with gestural interactions first produced more proposals (298) than subjects that were primed with tangible interactions first (246). Both trends however fell short of statistical significance (t-test, $p>0.05$).

We looked at the total number of interactions that were proposed for each task, and evaluated the mean number of interaction proposals per task category. A Friedman test revealed significant differences, and post-hoc Wilcoxon signed-rank tests were performed. Subjects produced significantly ($p<0.001$) more interactions for tasks of category TE (2.28 proposals on average) and TI (1.77) compared to tasks of category HO (1.15) and CB (0.88). The difference in the mean number of interactions for tasks of category TE compared to tasks of category TI is also statistically significant ($p<0.05$), see Figure 2.

Overall, we were able to elicit interaction proposals for each task. All subjects came up with pan interaction proposals for the primary

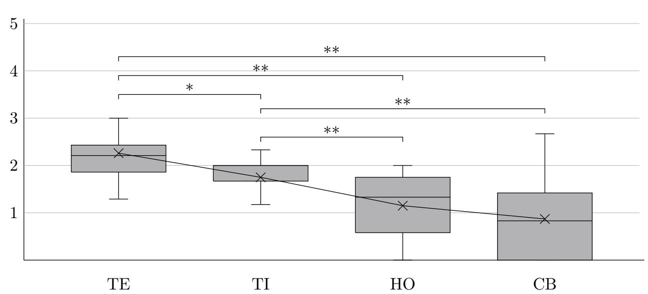

Figure 2: Boxplot of number of interaction proposals per subject per task. Marked differences are statistically significant on level $p<0.05$ (*) and $p<0.001$ (**), respectively

tasks related to temperature setting (TE) except for task TE16 ("turn off cooking zone"), where one subject expected automatic behavior. For all the other tasks of category TI, HO and CB, there were always at least two subjects that were not able to produce interaction proposals. Worst quotes were recorded for tasks of category CB, were 7 to 8 subjects did not come up with interaction proposals utilizing the pan.

Automatic behavior without explicit interaction was expected especially in TE16 "turn off cooking zone" (11), TE01 "turn on cooking zone" (7), TI09 "stop timer" (7) and HO10 "turn on cooker hood" (5). Proposals for automatic behavior occasionally also occurred for TI08 "start timer" (2), HO11 "increase cooker hood fan speed" (2) and HO12 "turn on light in the cooker hood" (2).

4.2 Type of produced interactions

All interaction proposals were manually annotated. We classified each proposal according to the underlying interaction paradigm (tangible vs. gestural). We further ranked the proposals for each subject and task according to the sum of goodness and ease evaluation. The first proposed interaction was ranked higher in case of equal sums.

More than two-third (385) of all 544 proposed interactions are classified as gestural interactions, while the remaining 159 interactions are classified as tangible interactions. Considering only the first interaction proposals, subjects came up with 180 gestural interactions, and 75 tangible interactions. The ratio is even higher for the best (i.e. highest ranked) interaction proposals, with 210 gestural interactions vs. 47 tangible interactions. All of these differences are statistically significant (t-test with unequal variances, $p<0.001$). Neither the used pan nor the order of priming affected the overall choice between gestural and tangible interactions significantly.

4.3 Classification of interaction proposals

Before classifying interactions in clusters, we had to split interaction proposals for TI07 ("set timer to 20:30") into parts. Subjects almost entirely accomplished TI07 in multiple steps, e.g. they performed an interaction to set the minutes, and then performed another interaction to set seconds. In 10 cases, subjects performed a dedicated interaction to enter the timer mode, and then set the timer with similar or identical interactions as in the previous temperature tasks. In 16 cases, the interactions that subjects proposed to set the timer differed from the interactions they proposed to set the temperature, and a dedicated activation timer mode was thus not necessary.

For each interaction (or sub-interaction in case of TI07), we provided a short written description (e.g. "double tap on top of the pan handle with the index finger") which served as major input for the subsequent clustering. Here, we followed the approach described e.g. by Chan et al. [3] and Piumsomboon et al. [17], and clustered interactions that were similar rather than identical. To give an example, the clustering does not differentiate between tapping on top of the pan handle with the index finger, and tapping on top with the thumb. Different fingers were deliberately chosen by some subjects to convey information (e.g. tapping with the thumb reduces cook top temperature, while tapping with the index finger increases temperature). In some other cases however, subjects

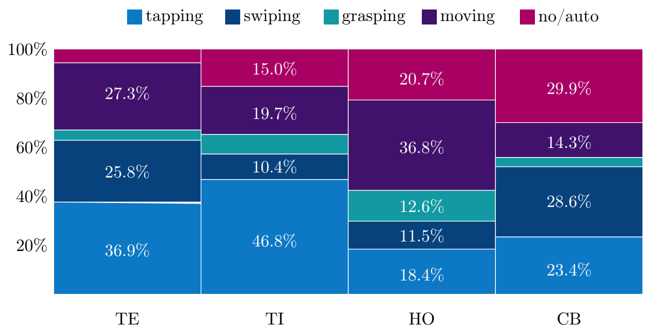

Figure 3: Action distribution for the different task categories (no/auto = no interaction proposal or automatic behavior expected)

mixed up which finger they used, e.g. they performed an interaction with a certain finger, and then used another one when they were asked to repeat the interaction. Here, our observation was comparable to that from Chan et al. [3]. We are of the opinion that our less restrictive clustering approach is suitable to "represent the thought behind gestures" [3]. However, in all cases where either finger type or location were crucial for the interaction, we explicitly made a notice in the written description to not lose this information when designing the final gesture set. Two authors clustered the interactions independently. In cases of discrepancy between the clusterings, we achieved consensus through discussion. As a result of clustering, we identified 41 different interactions with and on a pan, as illustrated in Figure 7

4.4 Actions

We discovered four basic action types: *tapping*, *swiping*, *grasping* and *moving*. *Tapping* incorporates tapping on the pan handle with one or multiple fingers without moving the pan, and *swiping* incorpoates swiping on the pan handle, respectively. *Grasping* interactions are all other interactions that are performed on the pan handle without moving the pan. Accordingly, all interactions where the pan is moved are assigned to the action type *moving*. As noted in the introduction, we refer to interactions that imply moving the pan as tangible interactions. *Tapping*, *swiping* and *grasping* interactions thus belong to the paradigm of gestural interactions, where the pan is not moved. In addition, the latter interactions utilize the pan handle surface for interaction, which supports the classification as gestural interactions (see e.g. [23]). The distribution of these actions for tasks per category is displayed in Figure 3.

Interactions involving *tapping* are the most common interactions, with 238 occurrences (from a total of 670 interactions, or sub-interactions in case of task 7, respectively). Subjects used each side of the pan handle (top, left, right, bottom, back) as input surface for tapping. Tapping on the left side of the pan handle was exclusively done with the thumb (note that all subjects held the pan in their right hand), and tapping on the right side of the pan handle was mostly done with the index finger, and occasionally with the middle finger. When tapping on the top surface, subjects used either thumb or index finger. More detailed statistics on finger usage are not meaningful due to the aforementioned observation that subjects occasionally mixed up the used finger.

For the top side, subjects occasionally used the pan handle as a scale to input certain values (the corresponding interaction icons in Figure 7 contain a scale illustration). For example, subjects mapped one end of the pan handle to a temperature level of 0 and the other end to a temperature level of 10, and then tapped on the corresponding position for temperature input. As an alternative, subjects often performed multiple discrete taps to set a certain value.

136 interactions involved *swiping* on the top, left or right side of the pan handle. One subject used the bottom of the pan handle as input surface for a swipe gesture, one subject performed a swiping gesture with the whole hand around the pan handle. Comparable to tapping, subjects occasionally used the top side of the pan handle as a scale for absolute input. Swiping on the left side was exclusively done with the thumb. Subjects used their thumb or index finger to swipe on the top side, and their index or middle finger to swipe on the right side of the pan handle.

Grasping interactions were least common across subjects, with only 42 occurrences (accounting for 6% of interactions). This includes holding or pressing the pan handle, but also taking a special hand posture (e.g. spreading thumb and index to form an 'L', while the other fingers grasp the pan handle). We assigned the interaction "lay flat hand on top of pan handle" (see also Figure 7) to this action type as well, considering this as the best fit. We also decided to assign the interaction "rotate grasping hand" to the action type *grasping* and not to *swiping*, as we hesitated to consider it as a classical swiping gesture.

The action type *moving* describes all tangible interactions where the pan is being moved. This includes e.g. rotating or translating the pan on the cook top, or lifting the pan to move it in free space. Some subjects produce tilting interactions, either by pushing down or lifting up the pan handle on the outer end. One subject tilted the pan by rotating it slightly around the pan handle axis. Subjects also used the pan to point towards specific areas, either using the pan handle as pointer, or oppositely directed using the pan as pointer. Lifting the pan and moving it towards an object (referred to as "lift and point") was frequently done for HO10 to turn on the cooker hood. Overall, 25% of all interaction proposals (168) belong to action type moving.

4.5 Consensus Gestures

According to our experimental design, subjects elicited multiple proposals for the same task. We used two metrics introduced by Morris [11] to capture the degree of agreement between subjects: Max-consensus describes the percent of subjects that propose the most frequently elicited interaction for a given task. The consensus-distinct ratio relates the percent of distinct interactions that achieve a certain consensus threshold to the total number of interaction proposals for a given task. In agreement with prior work [11], we selected a consensus threshold of 2. Both metrics for each task are shown in Figure 4.

We made some conspicuous observations for the consensus interactions (i.e. most frequently elicited interaction), especially for tasks of category TE. While our observation when conducting the

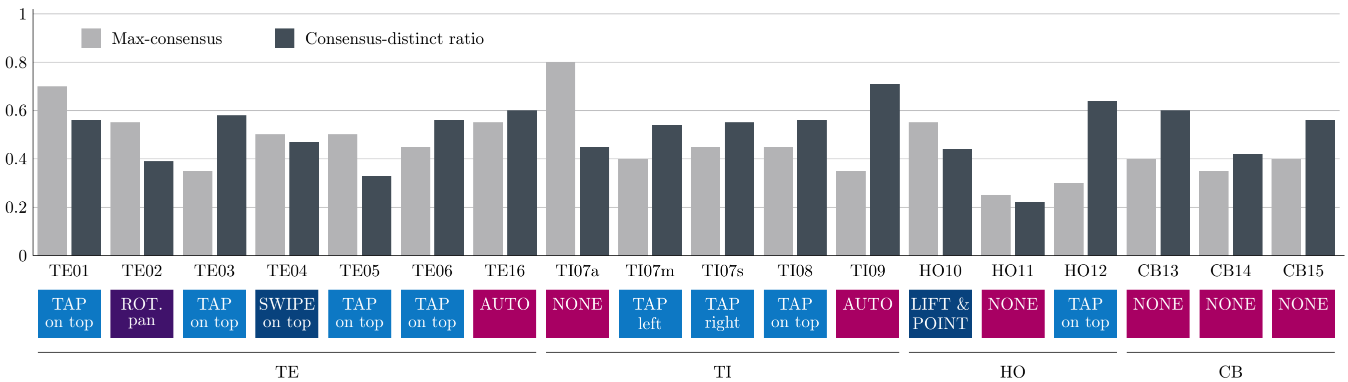

Figure 4: Max-consensus and consensus-distinct ratio for each task, including the most frequently proposed interaction for each task (colored according to the underlying action type). Interactions in task TI07 ("set timer to 20:30") are split into sub-interactions, i.e. "activate timer" (TI07a), "set minutes" (TI07m) and "set seconds" (TI07s)

study was that nearly all subjects proposed similar interactions for setting the different temperature levels, the consensus interactions for these tasks partially differed. We conducted a second analysis for all tasks of category TE, comprising also the second and third most frequently proposed interaction. As an outcome, the gestural interactions "tap on top" and "swipe on top" and the tangible interaction "rotate pan" are the three most frequently elicited interactions (in varying order) for all tasks that involve setting the cook top temperature. As a slight variation of the Max-consensus metric, we calculated the percent of subjects that proposed either one of these three interactions, leading to values between 0.75 and 0.85 for TE02 to TE06. In other words, 75-85% percent of subjects proposed either tapping or swiping on top of the pan handle, or rotating the pan to set the cook top temperature.

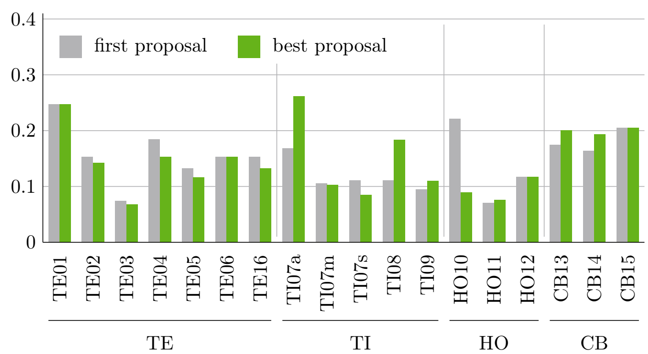

Figure 5: Agreement rates for the first and best proposal (in terms of self evaluated goodness) per task

4.6 Agreement among subjects

In order to compare our results with related studies, we calculated agreement rates AR according to Vatavu & Wobbrock [24], which is frequently used when analyzing elicitation studies. As the agreement rate calculation is only meaningful when subjects produce only one interaction per task, we calculated agreement rates for the first and for the best proposal of subjects (see Figure 5). The best proposal was the one that subjects ranked highest in terms of self evaluated goodness. When multiple proposals were on the same level of goodness, the first mentioned propsal was taken.

Agreement rates range from 0.066 (low agreement, $AR \leq 0.100$) to 0.261 (medium agreement, $0.100 < AR < 0.300$). The mean agreement rate both for the best and for the first interaction proposals is 0.147. Vatavu and Wobbrock [24] provide AR for 18 previous studies. From these 18 studies, only two have lower agreement rates ([10] and [20], both with mean AR of 0.108). Overall, agreement rates for the best and for the first interaction proposals are quite similar.

4.7 Subjective rating

In a follow-up questionnaire, subjects were asked to provide their feedback on the idea of controlling functions in the kitchen on/with a pan via two questions: (1) "I see an added value in using this system to interact with [. . .]", and (2) "For the interaction with [. . .], I would prefer the system over conventional controls". Both ratings were done for all 4 task categories on six-point Likert scales, ranging from 1 = "strongly disagree" to 6 = "strongly agree". Figure 6 shows boxplot of the subjective ratings. The rating is very positive for temperature control and slightly positive for timer control. For both cooker hood and digital cookbook, most subjects neither see an added value in using the pan, nor would prefer it over conventional control.

4.8 Further feedback from subjects

Throughout the study, subjects were engaged to think aloud. It is common practice to reflect on the qualitative results arising from subjects' feedback. However, when analyzing this feedback, we found that most of it either underlines the quantitative results (e.g. subjects verbally emphasizing the suitability of the pan handle for touch interaction), or relates to alternative interaction concepts (e.g. speech interaction), or relates to methodical issues (e.g. subjects complaining about lengthy temperature setting tasks). Here, we focus on the (admittedly rare) statements that go beyond these points and improve the pan interaction concept.

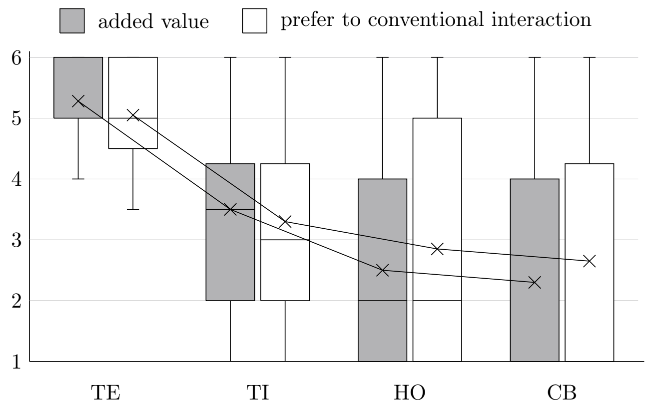

Figure 6: Boxplot and mean values of subjective rating of added value and preference on six-point Likert scales, ranging from 1 = "strongly disagree" to 6 = "strongly agree".

The most frequent argument against moving or rotating the pan was, that it is inconvenient when other pans or pots are used on the cook top at the same time. Remarks in this direction were made by nearly all subjects. Some subjects assumed that rotating the pan might not be ergonomic, especially when the pan handle is on the opposite side. One subject said that she always lifts her pan and avoids moving it over the cook top in order to prevent scratches.

One argument against tapping or swiping on the pan handle was that people run risk to burn their fingers, e.g. from hot oil. The strongest argument against using the handle for touch or swipe input (raised from one subject) was, that there is no analogous interaction concept for pots. Overall, arguments against tapping or swiping on the pan handle were rare compared to arguments against moving or rotating the pan.

5 DISCUSSION

5.1 Design guidelines for interacting with a pan

First and foremost, we were positively surprised about the number of different interaction proposals that users came up with for the comparably simple setup of interacting with a pan. The preferred interactions (based on number of naming, individual rating, inter-subject agreement and subjective feedback) however are the ones that might be most obvious, i.e. simple tapping or swiping on the pan handle or rotating the pan. The elicitation study now puts the initial assumptions on firm ground and provides additional valuable insights for the gesture set proposal.

A clear recommendation for interactions on/with a pan can be made for the primary cook top function related to setting the temperature. This is directly evident from the subjective ratings, and indirectly from the number of proposal that subjects came up with. The pan position clearly determines the addressed cooking zone. Gestural interactions seem to be better suited especially when multiple pans are placed on the cook top. Temperature adjustment can be easily made with subtle grasping microgestures, i.e. swiping or tapping with the thumb on the pan handle. The mapping of swipe direction and tap location to the direction of temperature change was consistent throughout all subjects for left/right, i.e. tapping left or swiping to the left for temperature decrease, and tapping right or swiping to the right for temperature increase. Swiping along the pan handle towards the pan (or tapping on a position closer to the pan, respectively) was mostly mapped to an increase of temperature (and vice versa to a decrease), while some subjects used the inverse mapping, i.e. swiping towards the pan to decrease temperature. The usage of these discrete tapping or swiping gestures is explicitly suitable for gradual temperature adjustments, e.g. reducing temperature by one level. Performing a discrete gesture multiple times for larger temperature changes is considered appropriate from subjects. For frequent temperature changing tasks, e.g. setting maximum temperature after turning on the cook top, subjects came up with shortcuts, e.g. double tapping or swiping left once.

Integration of peripheral functions (controlling the cooker hood or interacting with a digital cookbook) in the pan interaction concept cannot be recommended at this time. Subjects frequently refused to extensively think about an appropriate pan interaction proposal for tasks in these categories, thereby referring to the superiority of existing interaction concepts.

The picture is somewhat ambivalent when it comes to timer functions. Some subjects proposed interactions that explicitly differed from the temperature-related task. In this case, tapping or swiping on the left side of the pan handle was frequently used for setting the minutes, and tapping or swiping on the right side of the pan handle was used for setting the seconds accordingly. As these interactions specify the context, a subsequent tap on the pan handle starts the timer. At the same time, some other subjects came up with a menu-based approach, using a certain gesture (often involving tapping on the top of the pan handle) to toggle through a visualized menu and select the timer function. Setting the timer was then often accomplished with the same interactions that were used to set the temperature before, e.g. swiping or tapping on the top side of the pan handle. Surprisingly, subjects that came up with a menu-based proposal only rarely proposed to integrate cooker hood functions or functions related to the digital cook book into the menu.

It is worth recalling that the structure of the pan handle (despite the existing differences between the two pans) did not affect the proposed interaction types. For example, subjects tapped on the red, structured pan handle roughly as often as on the white, unstructured pan handle. The main difference was that the graspable landmarks of the red pan handle concentrated user taps or swipes on a certain position, whereas the exact contact points on the white pan handle showed more variance. It can be expected that a microgesture-based interaction concept is suitable on all pan handles.

No final statement can be made on the generalizabilty of the interaction concept e.g. to pots. Microgestures might work on pot handles as well, but this needs to be investigated in detail. However, in any case it is worth recalling that the microgesture-based interaction concept is an *additional* but not exclusive way to interact with a cook top, and conventional control elements will still be present.

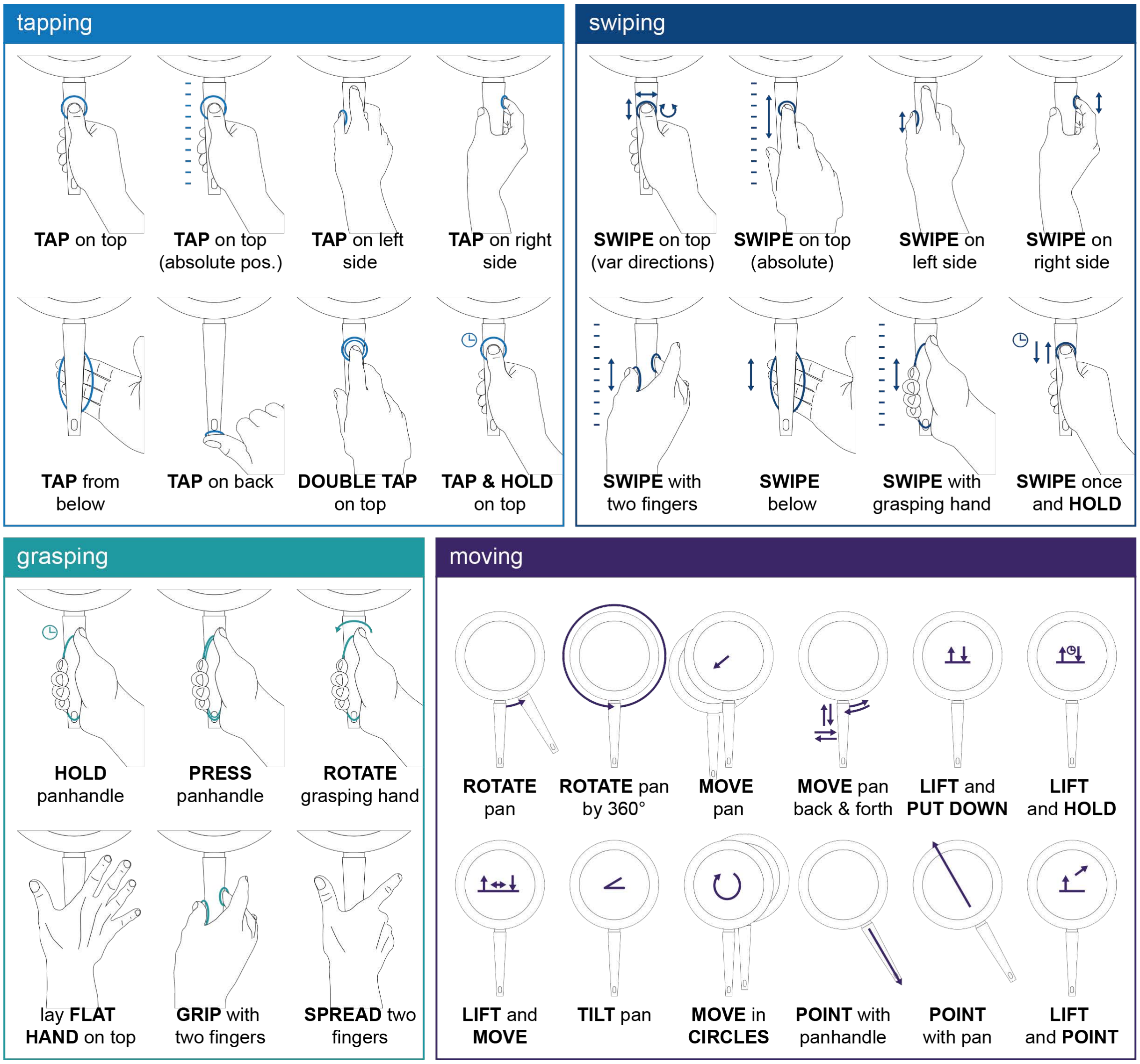

Figure 7: Overview of elicited interactions, grouped according to underlying action type

5.2 Practical recommendation

In summary, we interpret subjects' feedback also as a reminder to keep the interaction concept simple and not overload it with additional functions. Based especially on the findings on consensus gestures and subjective feedback, we currently recommend the microgesture-based interaction concept only for the primary tasks of setting temperature.

A coherent gesture set is to use tapping on the pan handle for temperature control. The top surface of the pan handle was frequently used for tapping. It is recommended to use the top surface both for temperature increase and decrease, e.g. tapping on the right half of the top surface for temperature increase, and on the left half of the top surface for decrease, respectively. Each tap increases (or decreases) temperature in discrete steps. As multiple taps are thus performed to adjust the temperature over mutiple levels, we do not recommend double tapping as a shortcut (e.g. to set the temperature to maximum). Instead, tap and hold can be used for rapid temperature adjustment over multiple levels, accompanied with visual feedback.

5.3 Methodical discussion

Our study was conducted in a lab environment and not under environmental conditions of real cooking. We took some measures to compensate (e.g. the lab resembles a real home environment with a kitchen), but real cooking definitely comes with additional requirements. However, we feel that subjects successfully put themselves mentally in a real cooking condition, which allowed them to provide additional valuable insights, as described in the results section. In fact, these insights provided the strongest arguments against tangible interactions.

We deliberately did not randomize tasks and confronted all subjects with tasks in the same order, which is a noticeable difference to related studies. We have no reason to believe that this affected the interaction proposals. We frequently observed that subjects came back to an already accomplished task and provided an additional interaction proposal that they conceived during a later task. Even contrary, we assume that there would have been a certain risk to "loose" subjects when confronting them with an uncommon task in the beginning. One drawback of not randomizing task was that some subjects started to get bored after subsequent temperature setting tasks. We deliberately selected tasks to cover all scenarios, i.e. increasing or decreasing temperature by one or multiple levels. However, subjects often took a more holistic view, considering not only the single task but all possible temperature selection tasks as a whole.

Subjects always had to put the pan on the top left cooking zone. This ensured that the pan and the users' hand (all subjects interacted with the right hand) was always ideally visible for the camera. The cook top was embedded in a freestanding kitchen island. We are aware that this constitutes an optimal setting for the study, and that accessibility from all sides might be rarely given in real world. Subjects occasionally pointed to this restriction. If at all, we consider this as an impeding factor for tangible interactions, and not for gestural interactions.

Using production and asking subjects to come up with multiple proposals improved the outcome of the study. The first interaction proposal was not always the best one (as measured by subjects' ratings). It's still worth mentioning that AR as metric did not differ when using the first interactions compared to the best interactions. In other words, AR alone is not sufficient to value the outcome of an elicitation study.

5.4 Future work

Future work will include the implementation of an interactive system based on the elicited interactions, taking the design guidelines into account. We believe that a follow-up study should be conducted under even more realistic cooking conditions, involving real cooking. This will enable testing of the hypothesis that pan-based interactions can be seamlessly integrated in the cooking process.

While the elicitation study focused on user input, we got valuable feedback on system output as well, which will be part of future work. Subjects consistently stated that some sort of visual feedback is essential, or at least greatly simplifies interactions that are made with a pan. Proposals range from conventional (seven-segment) displays to projected visualization augmenting the pan.

Going beyond the pan-cook top example, we believe that a deeper investigation of further examples of object and system with natural functional relation (including a formal definiton of this concept), as briefly raised in the introduction, is very promising. The concrete interaction proposals derived in this study can certainly not be directly transferred to e.g. the task of controlling coffee machine functions with tangible or gestural interactions on/with a coffee cup. One of the indirect results of this study, i.e. to pay attention not to overload an interaction concept based on repurposed objects, might however be valid for the coffee machine / coffee cup example as well.

6 CONCLUSION

This paper presented a user elicitation study to identify which interactions subjects perform on or with a pan to control functions related to cooking. Neither the order of priming nor differences in the used pan handle affected the results. While subjects provided a huge variety of different interaction proposals, we identified a general consensus for comparably obvious interactions, which was to be expected. Subjects report a clear added value when primary cook top functions, i.e. adjusting the temperature, are accomplished with a pan-based interaction concept. For functions that are not directly related to the cook top, subjects show a skeptical or even rejecting attitude.

For an interaction designer, universal applicability of a novel interaction concept for versatile functions or tasks might be desirable for understandable reasons. The elicitation study clearly pointed out the strengths of the novel interaction concept based on tangible or gestural interactions with a pan, while at the same time reminding us not to overload the concept.

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