Designing for Capacities Rather Than Disabilities

Investigating the relationship between psychomotor capacities and interaction opportunities

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***Abstract*— This paper explores how designing based on psychomotor capacities instead of disabilities can reconnect old people with technology. We introduce four alternative designs for radios to demonstrate how facilitating a design process that acknowledges psychomotor challenges associated with aging can both help participants rediscover their own psychomotor capacities and simultaneously re-establish meaningful interaction. The paper presents findings from quantitative analysis of performance testing and qualitative analysis from reflection activities involving 65 participants over four years. We use our findings in a discussion of how we can incorporate knowledge about the participants' psychomotor capacities in the design process to help design artifacts that can prolong interaction.**

Keywords — psychomotor abilities; elderly; radio; assistive technology.

I. INTRODUCTION

The radio is an important device to many. This is particularly the case for the oldest generation in Norway where the radio is one of the most appreciated and well-used devices among older adults. In a local care home in Oslo (with the average resident age of 84 years), which was part of our empirical context, we observed that 91% of the 90 elderly residents had a radio device in the home that they would use on an average day. However, most radios are operated by the use of hands and fingers and rely on psychomotor capacities that may decline during old age [1]. Not acknowledging such bodily changes may complicate or prevent interaction with technology. Our prior studies have demonstrated how something seemingly simple as a radio is not considered as simple or functional when aging symptoms appear [2].

This paper aims at investigating how a better understanding of both psychomotor abilities and disabilities can help inform the design process and aid people re-establish and prolong interaction with radios. Our aim is to shift the design process from revolving around disabilities and instead acknowledge that despite declining functional abilities all people still inhabit psychomotor capacities that can be utilized in the design process. By collaborating with participants who are no longer able to operate commercial radios, we have co-designed four radios and used them to explore opportunities for them to re-enable their interaction with radios. We present four different functioning radios that are specifically designed for older people and discuss the psychomotor properties of these interfaces regarding the interaction opportunities they offer. Our study involved 65 participants who contributed to our research between 2013-2016. To anchor our understanding of how these physical changes manifest themselves, we apply Fleishman's taxonomy of psychomotor abilities and skills [3] to identify, measure, and discuss the participants' ability to operate the four different radios. The paper presents two phases of an investigation focusing on a various aspect of the relationship between psychomotor abilities and interaction with radios. The first phase includes a statistical analysis of performance testing of three of the four radios. The results are used to demonstrate how various participants preferred different interfaces based on their psychomotor capacities, and how participants with motor challenges in certain cases were able to match the performance of older adults without these difficulties. The second phase included three activities where participants explored and assessed their own psychomotor capacities – both individually and in groups – and provides insight into how participants experienced interacting with the four radios and what actions and interfaces that proved the most challenging.

The paper is structured as follows. We introduce the motivation for focusing on the radio in Section II. In Section III, related work on psychomotor and age-related studies within HCI is presented, while Section IV covers the taxonomy used to describe and measure psychomotor abilities. The two phases and involved research methods, as well as the four developed radios, are outlined in Section V followed by results and analysis in Section VI. The paper ends with a discussion where we argue that both the design result and the design process can benefit from acknowledging the psychomotor challenges associated with old age.

II. BACKGROUND

According to statistics from Statistics Norway (SSB), the older part of the population (aged 67-79) remains stable in the national average of radio listening in Norway [4]. The red line in Figure 1 shows an overview of the mean percentage of the population who listens to the radio while the blue line shows the corresponding percentage for people aged 67-79.

The number of minutes in average spent listening to the radio is illustrated in Figure 2, and as we can read from the graph, there is only one recorded case in the past 23 years (1997) where the elderly fraction of the population on average would listen less to the radio compared to the general population. We can also read from Figures 1 and 2 that even in years where the number of elderly radio listeners was lower than the national average (i.e., 1994, 1995, 2001, 2009, and 2010), the number of minutes spent in front of the radio was higher for the elderly radio listeners. The difference between the older generation and the rest of the population seems to have diverged over time, and the difference in a ten-year perspective is now greater than ever. The mean difference between the amount of time the elderly used for radio listening compared with the rest of the population in the period from 1991 to 2000 was 7.0 minutes while the corresponding difference in the period from 2005 to 2014 was over four times larger (33.1 minutes). This difference demonstrates an interesting phenomenon, namely that the radio as a piece of technology is not on its way to extinction. Quite the contrary, they are on the rise again regarding both share of the population that listens to the radio (Figure 1), and the number of minutes spent in front of the radio per day (Figure 2).

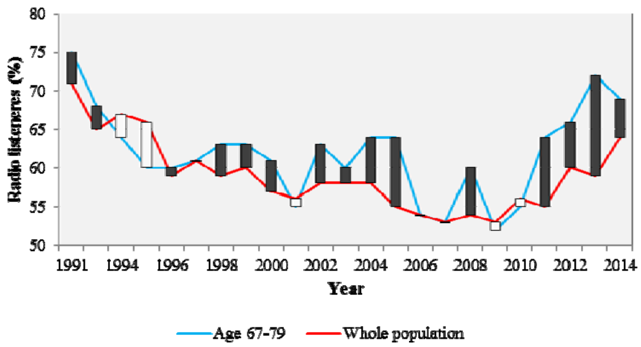

Figure 1. Percentage of population listening to the radio on an average day

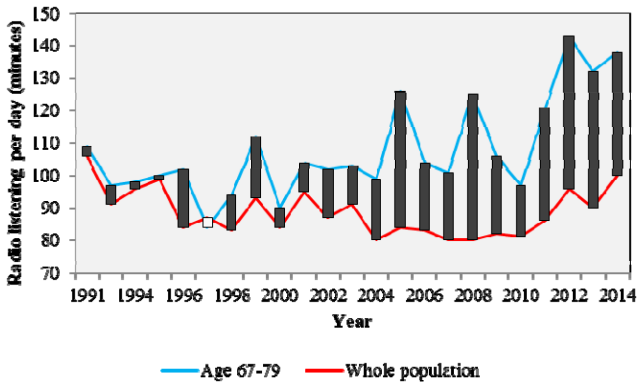

Figure 2. Number of minutes spent listening to the radio on an average day

In our prior research (e.g., [5] and [2]) we have discussed aspects of the role technology has in the lives of older adults. We have touched upon related topics such as the social importance of being able to operate communicative technologies such as radios to stay in touch with the outside world [5]. We also explored deeper issues concerning the ability to operate such devices and the way such devices are presented, e.g., design that is oversimplified or stigmatizing [2]. These studies have concentrated on the experience of interacting with technology and would consequently be better suited to further discuss the social and contextual aspects of interaction with technologies, for instance, loneliness and boredom. However, in this paper, the focus remains on the psychomotor ability to interact with the radio, and more precisely re-establishing a lost relationship between old users and technology.

III. RELATED WORK

A long time has passed since researchers began systematically investigating the relationship between aging-related disabilities such as arthritis and the ability to interact with computers [6]. Morgan et al. [7] described significant differences in the execution of movement when comparing young adults with older adults, and more precisely the speed, sub-movements, and smoothness in movement. Similarly, Riviere & Thakor [8] use a comparative study between young, old, and motor-disabled subjects with regards to performance when operating tracking with a computer mouse. Their study claims that both aging and motor disability affect performance by increasing the inaccuracy and nonlinearity. Age has an apparent impact on our ability to interact and the extent to which we are able to adapt to new interaction mechanisms. This partly manifests itself through changes in psychomotor capacities. A recent study [9] claims the existence of age-related differences in the strategic repertoire, distribution, and execution within the sensorimotor domain. Regardless of the age of the intended user group, fine psychomotor abilities should be included in the determining of successful interactions [10].

One of the very few laws that attempt to descriptively explain the psychomotor role of human-computer interaction through mathematical formulas is Fitts' law. The original model was formulated over six decades ago and attempted described the linear relationship between movement time and index of difficulty. The model is still used today to quantify the difficulty of performing tasks and was in 2002 included in the ISO standard ISO 9241-9, which concerns non-keyboard input devices. However, since its conception, the model has undergone several modifications and refinements and does not pertain a universally accepted formulation today [11]. A shortcoming of Fitts' law is its ability to properly determine and evaluate differently observed result in the psychomotor performance when studying different task types, varying motor skills and differences in motor performance [12]. Others have argued that there are several factors affecting our endpoint performance not adequately captured in the mathematical model [13].

In the context of aging, studies on how psychomotor abilities affect user performance with computer tasks within the field of HCI can also be traced back to at least the early 90s where researchers claimed and studied a relationship between the two [8]. Studies have been conducted within the field of HCI focusing on traditional interfaces, including WIMP and trackpads. For instance, psychomotor skills are an essential part of the ability to operate a computer mouse, and several studies have investigated the relation between psychomotor abilities and use performance operating a mouse or trackpad [6][10][14]-[17]. Common for most of these studies is that they include several components that make up the list of psychomotor abilities described in Fleishman taxonomy, e.g., precision control, arm-hand steadiness, manual dexterity and wrist-finger speed [13].

Previous exploration of various input mechanisms and the physical properties of the design also contributes to our research. For instance, the research of [18] argues that proper understanding of materials used in the design can help support habits and reinforce competences; hence, the exploration of input mechanisms and modes of operation becomes important to the understanding and experience during use. The aging process introduces changes to cognitive and bodily capacities that may complicate or extend the training required to incorporate new interaction mechanisms or patterns [19]. Similarly, the importance of acknowledging the strong relationship between the design and the homely environment has been the emphasis of several studies, e.g., [20, 21], and we have seen similar tendencies in our own prior explorations [2]. Several studies have argued for a strong relationship between material attributes and the perceived experience of digital devices [22]-[24], and that wrongful use of materials can by itself contribute to people withstanding from engaging with technology [20, 25]. We have also conducted exploration of materials in design within our empirical context and investigated the role of materials in perceived familiarity and context-adaptability [21, 26].

IV. PSYCHOMOTOR ABILITIES

People undergo multiple reductions in both cognitive and motor skills as when entering later stages of life. In this study, we have chosen to focus on reduced psychomotor capacities in the hands and fingers, and how these changes affect the likeability to interact with radios. We have chosen not to describe this shift as a limitation in the ability to interact since that would indicate an impossibility in the interaction between these individuals and the radio as technology. Instead, we believe that despite the undeniable changes in bodily capacities, our ability to interact with technology is not deprived, or necessarily not even reduced. We aim to demonstrate how adapting the technology to these changes in physical capacities can prolong and re-establish interaction. Nevertheless, the focus of this study is older people with symptoms, illnesses, and diagnoses associated with reduced capabilities in the hands and fingers. This includes individual types of rheumatic disorders associated with hands and fingers, osteoarthritis, as well as more general motor system disabilities such as Parkinson's disease. Non-diagnosed older adults showing symptoms affecting hands and fingers, such as trembling, involuntary movements, spasms were also included, as fine motor skills tend to decline with age [27]. We expanded our experimental group with elderly people claiming inability to operate radios, despite not being able to provide a medical record of a specific disability, as challenges associated with aging like inadequate blood flow and circulation to the muscles, injuries, stress, fatigue may also produce spasm in muscles that would reduce the psychomotor capacities. Several residents in our empirical context also reported similar symptoms of cramps from medical side effects, in particular from medication related to Parkinson's disease and Osteoporosis. Other types of developmental or genetic disorders that may have an impact on psychomotor capabilities, but that are not particularly prominent symptoms among the older adults, were not included in this study (e.g., Down's syndrome, cerebral palsy and dystonia).

A. *Fleishman's taxonomy*

Based on cognitive, sensory, physical, and psychomotor factors, Fleishman derived 52 skills and abilities describing human performance. Although this model was initially developed for a job-related environment, the taxonomy of Fleishman describes abilities and skills that can be associated with performance in everyday tasks [28]. The taxonomy separates abilities from skills; abilities are defined as characteristics and traits shaped throughout the first phase of our lives while skills describe the degree to which we can effectively carry out an action directly related to a given task. Common for the two is that both skills and abilities related to psychomotor capacities involve complex movement patterns and require practice and maintenance in order to remain intact [29].

As the aging process does not follow a schematic or linear development, it is hard to consider any abilities or skills as less relevant than others. For instance, the cognitive factor constitutes the biggest share of skills and abilities and is obviously relevant also in the discussion of aging-related reduction of interaction capacities. It is further apparent that some of the motoric challenges stem from changes in the cognitive capacities, e.g., ideomotor apraxia where changes in semantic memory capacity reduce the ability to plan or complete motor actions. Studying this category involves abilities and skills that fuse cognitive, perceptual and physical abilities [30].

Studies that focus on older adults with motor challenges in their hands tend to carry an increased attention towards the abilities and skills that fall under the taxonomic category of physical factors. This is because the muscular restrictions and reduced bodily capabilities in the hands mainly tend to affect the abilities and skills covered by this category. Examples of abilities and skills included in this category are stamina, physical strength and flexibility, balance, and coordination. In previous studies of digital devices in the context of older adults, we have been concerned with both stamina and physical strength (e.g., in [2]), but in this paper, we mainly focus on psychomotor factors. This is because most of the actions associated with the operation of a radio and other similar digital devices require movement and a configuration of hands and body that relies on the ability to combine physical movement with cognitive functions. Thus, psychomotor factors constitute our main interest, as this organically includes physical skills such as coordination, dexterity, reaction and manipulation. Unlike physical factors, psychomotor factors are also subjected to the influence of reduction in skills and abilities associated with secondary categories; psychomotor capacities often depend on a supportive capacity in addition to the physical. A reduction in other seemingly unrelated features (e.g., visual impairment) may, as Jacko & Vitense [30] point out, have an impact on psychomotor skills.

B. *Scope*

Our study is limited to psychomotor challenges of hands and fingers. Due to inadequate access to fully medically-assessed participants, as well as claimed expertise, we do not address the impact of the decline in cognitive abilities and skills in this paper (e.g., dementia, depression, and forgetfulness). Our scope does not allow us to identify the best interfaces for a given disease but instead let us study the relationship and possible correlation between motor challenges and performance when interacting with radio interfaces. Nor do we want to identify all skills and abilities that are included in the performance of work-related tasks;

Figure 3. The four radios included in the study

we aim to identify the specific abilities and skills that are involved in the operation of radios, and affected by reduced capacity in the hands and fingers. Abilities and skills in the taxonomy of Fleishmann are described as independent of each other [13], and it should consequently be possible only to study a selection of these. A similar approach has been conducted in prior research, more specifically in the research of [13, 15, 16, 17]. Table I gives an overview of the psychomotor abilities included in our study. A description is provided for each ability based on the original taxonomy of Fleishman [3] in the right column of the table.

TABLE I. OVERVIEW OF PSYCHOMOTOR ABILITIES

Psychomotor ability	Description
Precision control	Ability to move control and the degree to which they can be moved quickly and repeatedly to exact positions.
Arm-hand steadiness	Ability to keep the hand and arm steady, both when suspended in air and while moving. Independent of strength and speed.
Manual dexterity	Ability to make quick and skillful coordinated movements with arms and one or both hands, as well as the ability to assemble, grab and move objects.
Finger dexterity	Ability to make quick, skillful, and coordinated movements with fingers of one or both hands.
Wrist-finger speed	Ability to repeat fast movements with wrist and fingers.
Multi-limb coordination	Ability to use two or more limbs simultaneously to coordinate movements when the body is not in motion.

While all the abilities and skills described in the psychomotor category of the taxonomy are relevant in a broader scope, we have excluded certain abilities and skills from our test. These are abilities that are not relevant for our purposes, and the decision is taken by both the physical challenges we are focusing on, and the digital components and interfaces included in the study. Not all abilities are relevant for the operation of our radios; hence, measuring these abilities would be difficult with the radios. More precisely, rate control, reaction time, speed of limb movement, and response orientation have been excluded. The reason is that these four abilities are not directly determining the capacity to interact with our four radios, but instead, describe the degree to which we can interact with them, as well as the performance during use. Rate control is not appropriate in situations where speed and direction of an object are perfectly predictable [30] while the other three (reaction time, speed of limb movement, and orientation response) mainly concern efficiency of performance, rather than the distinctive ability to perform them. Also, both reaction time and response orientation are intended to capture our reaction to a given signal and our ability to quickly initiate the response routine, something which would be unnatural in a context where our participants are testing our radios. Thus, these four abilities have not been included in our tests.

V. RESEARCH METHOD

A. *Radio #1*

The first radio is the top-left radio in Figure 3, and it was developed in 2013. The focus of the radio is to provide an interface that provides users with similar experiences and interaction mechanisms as they are used to from their traditional radios. The feedback one gets from operating radio is reminiscent of interaction found in traditional radios with a distinct response to actions. The focus has also been on finding the materials that provide the best grip and resistance during the interaction. We have explored the properties of various materials (wood, steel, plastic) to find the best functioning design for the knobs. The main interaction takes place by turning on a coarse switch that clearly snaps in place when selecting the channel. A second switch is used to adjust the volume.

B. *Radio #2*

The second radio is the top-right radio from Figure 3, and was developed in 2014. This radio depends on physical interaction and does not use traditional switches or buttons. As with the other two radios, this radio is also screenless. The user operates the radio with the use of wooden cubes with built-in Near Field Communication (NFC) chips. The NFC chips are preconfigured with a given radio channel, and by placing these physical cubes on top of the radio, one interacts with the interface. By placing a piece with a given channel on top of the radio starts playing. Removing the cube ends the playback. The focus has been on designing a radio that does not require fine motor skills in fingers. During the design process, material, weight, size and shape were explored in consultation with users to find the best objects for physical operation of the radio.

C. *Radio #3*

The third radio is the bottom-left radio in Figure 3, and was developed in 2015. The purpose of this radio was to allow users with tremors, involuntary twitching, and reduced fine motor skills to operate it. The radio is made of oak and has an aluminum cylinder with a wooden knob that automatically snaps to predefined positions using magnets. One operates the radio by positioning the wooden knob at a predefined position. A secondary exploratory feature is that the wooden knob swivels around the cylinder. The design of the radio offers deliberate constraints that prevent users from making mistakes during the interaction. The wooden knob is locked to the pole and the magnet in the cylinder both guides and limits the positioning. This allows involuntary actions to have less impact on the accuracy.

D. Radio #4

The fourth radio is the bottom-right radio in Figure 3, and was developed in 2016. The radio is made of wood and covered with pearl gray oak to blend into homely environments. A simple slider allows adjustment of volume while the pods represent radio channels or podcasts similar to Radio #2. Circular pods are placed in a hollowed and lowered circle to initiate the radio and removing the pods ends the operation. RFID tags are used to communicate between pods and the radio. The pods are coated with soft felt fabrics with strong colors and contrast to help guide the channel selection. The design of the pods is meant to be strong, durable, and easily graspable for people with a reduction in dexterity and motor challenges.

E. Research design

This study was divided into two phases. Our two phases included 65 participants in total, with 52 participating during the first phase and 13 participating during the second phase. The requirement for participation during both phases was that the participant suffered from reduced ability or no ability to operate a store-bought radio and thus needed a more customized interface. The three store-bought radios used for participant selection were Pinell Supersound DAB, Pop DAB Radio and Argon DAB Radio, three highly popular brands in Norway. The data for this study was collected in the period 2013-2016. The four radios used in this study were also built during the same period.

The first phase emphasized statistical analysis of psychomotor performance tied to the three first radios, i.e., Radio #1-3. The goal was to explore whether participants were able to interact with our alternative radio designs and how their performance scored compared to an independent control group. The second phase revolved around three activities, and we relied on qualitative methods to get the participants to reflect upon their own psychomotor capacities. This phase introduced Radio #4 as both a fourth alternative design and a thinking tool to help participants explore, assess, and discuss their psychomotor interaction challenges and opportunities.

This study was conducted at three local care facilities in Oslo. Each care facility consists of a set of apartments, with the largest holding 90 apartments. The care facilities consist of senior residents residing in independent apartments, but with shared access to a range of facilities, e.g., cafeteria, lounge, fitness center, and 24-hour staffed reception. The limited access to participants with motor challenges in hands and fingers led to four years of data gathering in order to yield an appropriate set of data.

F. Phase 1: Performance testing of psychomotor abilities

39 participants (M = 82.1 years, SD = 6.31) participated in six tests of Radio #1-3. For each test, we recruited an independent control group consisting of 13 older adults with no apparent motor disabilities (M = 80.4 years, SD = 5.29) who were asked to perform the same tasks as the experimental group. The testing in the first phase involved 52 participants in total. Most people had medical documentation to assess their motor disabilities. The documentation was provided to us by themselves or by the local care home administration with their consent. A few participants unable to operate store-bought radios and in the lack of proper medical documentation of disability were also invited to participate in the experimental group as they showed symptoms similar to those with proper diagnoses. Table II gives an overview of the participants and the documented or self-assessed disability or illness.

TABLE II. OVERVIEW OF PARTICIPANT GROUPS IN PHASE 1

Disability or illness	**N**
Cramps	8
Muscle stiffness	3
Osteoarthritis	8
Parkinson's disease	4
Rheumatoid arthritis	3
Tremor	13
Control group	13
Total	**52**

The participants in both groups were asked to interact with the three radios Radio #1-3 through a series of repeated tasks to measure their psychomotor performance. Three different tables and eight chairs were used to provide all participants with a setup that supported their preferred bodily configuration. Some participants were also sitting in their wheelchairs during the test, specifically three participants from the experimental group and one participant from the control group. For each of the radios, the participants were given a set of tasks that mimicked the context applicable parts of assignments given in standardized tests of psychomotor abilities, e.g., rotary pursuit test, steadiness tester, Minnesota manual dexterity test, Purdue pegboard, tapping board (as seen in [13], as well as O'Connor finger dexterity test, box and block test, Jebsen hand function test, and Moberg pick-up test. We also took into consideration the values embedded into psychomotor abilities defined in prior research, e.g. some of the skills defined by [29] such as timing, response ability, and speed, as well as the tasks presented in [12], most notably steadiness and aim.

As we used our own set of tasks, the results are not meant to demonstrate the external validity and be directly comparable to other test results, but instead provide a set of tasks applicable to the four radios, thereby providing us with a measurement comparable within the study. To eliminate learning effects and bias due to unfamiliarity with novel interaction mechanisms, each participant was given a demonstration of the intended interaction of each radio, and each participant conducted ten trials for each radio (similar to [6]). The task order was randomized for each participant. We relied on randomized repeated measures to minimize bias due to interpersonal variations between tests. The task set consisted of 12 tasks: gripping, turning, positioning, re-positioning, and resetting the main and secondary interaction element, as well as lifting and moving the radio. Time (seconds), error (count) and precision (position and distance) were observed and measured for each task, and the performance was graded on a normalized scale from 1-10 to make the performance metrics comparable. The computationally-generated normalized score used the four metrics above (seconds, count, position, and distance) to calculate the final score. Thus, the performance scores are not intended to be comparable beyond the scope of our research. In Figure 4, we see two participants from the experimental group testing the positioning and re-positioning of the main interaction element for Radio #2.

Figure 4. Two residents participating in psychomotor measurements

G. *Phase 2: Reflection on psychomotor abilities*

The second phase continued the exploration of how 13 participants (M = 81.1 years, SD = 5.5) – who were recruited following the exact same participation requirements as during the first phase – experienced the radios. Table III provides an overview of the participants who contributed to the second phase. The goal of this phase was to facilitate environments for participants to both individually and collectively explore, assess, and discuss their own psychomotor capacities. This was achieved by investigating how different modes of input affected the operating of the three radios introduced during the first phase, as well as through an exploration of a newly introduced fourth radio (Radio #4). Four participants in the second phase had previously been part of the experimental group of the first phase, and to allow them to continue their exploration we introduced a fourth radio as a new alternative. The second phase consisted of three main activities; (1) think-aloud testing of Radio #4, (2) semi-structured demonstrative interview, and (3) input device workshop. All 13 participants took part in all three activities. All three activities yielded qualitative feedback that supplemented the quantitative results from the previous phase.

TABLE III. OVERVIEW OF PARTICIPANT GROUPS IN PHASE 2

Disability or illness	N
Cramps	3
Muscle stiffness	2
Rheumatoid arthritis	4
Tremor	4
Total	**13**

The first activity was the think-aloud testing of the fourth radio. This radio was new to all participants, including those who had participated previously. The participants were asked to follow the same 12 randomly-ordered tasks as those used during the first phase where Radio #1-3 were evaluated. Rather than measuring time, error, or precision like we emphasized during the first phase, we gave the participants space to explain the details they perceived as most important as we moved along the tasks. Our experience from the former phase suggested that not all tasks were seen as equally difficult or interesting; we expected the distribution of time and attention to not be portioned equally across the 12 tasks amongst the participants. The testing was conducted in 13 single-sessions.

Following the think-aloud testing, we conducted a semi-structured demonstrative interview with where we asked all 13 participants to demonstrate challenges with the four radios and elaborate on the main difficulties during the interaction. We also structured parts of the interview to concentrate on those tasks and interaction forms that the participants mastered. We did not provide any tasks or present the radios in a particular order; the participants were free to use any radio or any task to demonstrate their experienced challenges and mastery. As we had previously seen wide ranges of physical and cognitive endurance in participation during similar activities [31] we did not enforce any time limits; the participants were free to participate for as long as they desired themselves. Due to these practical limitations with participation, these interviews were held in single sessions or with small groups.

The final activity was a workshop conducted in two sessions with five and eight participants respectively and gave the participants an opportunity to explore various input mechanisms for the four radios. To accommodate the workshop, we brought various elements that were compatible with the four radios such as different types of knobs, wheels, blocks and rings. The different components were of different shapes, sizes, textures, and materials and represented the variety of physical options. We organized this exploration as a workshop to help the participants learn about their own psychomotor capacities before making any comments or self-assessments as purely interview-based exploration might have yielded gender-based biases as found by [28] who suggested a tendency of men estimating their own capacities higher than their female counterparts. The workshop followed a similar structure as we had previously facilitated in [21, 26] where we focused on the exploration of various material components. Participants were asked to first freely explore and discuss the various components before presenting their favorites to the rest of the group. A selection of the components is depicted in Figure 5.

Figure 5: A selection of components used during the input device workshop

VI. RESULTS AND ANALYSIS

A. *Phase 1: Performance testing of psychomotor abilities*

The means and standard deviations for the psychomotor performance on a normalized scale from 1-10 across both groups are shown in Table IV. As expected, the control group had a better performance relatively compared to the experimental group across all three radios. The variation was larger for the control group, and we can read from the table that both groups demonstrated a similar within-group performance for each of the three radios. The average performance score was 7.43 (SD = 0.32) for the control group while it was 4.60 (SD = 0.22) for the experimental group. In Figure 6, we present the estimated marginal means for the control group vs. the regular group for all three radios.

TABLE IV. PSYCHOMOTOR PERFORMANCE SCORE

Radio #	Group	Mean	Std. Deviation	Lower Bound	Upper Bound	N
1	Control	7.385	.7372	6.730	8.039	13
	Experimental	4.517	1.2824	6.471	7.658	39
2	Control	7.064	.5755	7.156	8.536	13
	Experimental	4.389	1.1787	4.139	4.895	39
3	Control	7.846	.4328	4.046	4.732	13
	Experimental	4.897	1.4000	4.499	5.296	39

A 2 (group: selection or control) x 3 (radio: #1, #2 or #3) between-subjects analysis of variance (ANOVA) was conducted to study the psychomotor performance between the three radios as a function of the performance. We registered significant main effects of group, $F(1,150) = 173.6$, $p < .005$, $n = .536$, and radio, $F(2,150) = 3.1$, $p = .048$, $n = .040$. The main effects were not qualified by an interaction between group and radio, $F(2,150) = 0.142$, $p = 0.867$, $\eta p^2 = .002$. The participants in the selection group (M = 4.601, SD = .107) had significantly lower performance than the participants in the control group (M = 7.432, SD = .186). The analysis also revealed a slightly lower performance difference between the three radios: (M = 5.951, SD = .186), (M = 5.726, SD = .186), and (M = 6.372, SD = .186). Levene's test for equality of variances was found to be violated for the present analysis ($p = .001$), and Bonferroni post-hoc analysis for the radios showed that Radio #2 had significantly lower performance than Radio #3 at the .05 level, while differences between Radios #1 and #2 and Radios #1 and #3 were not significant.

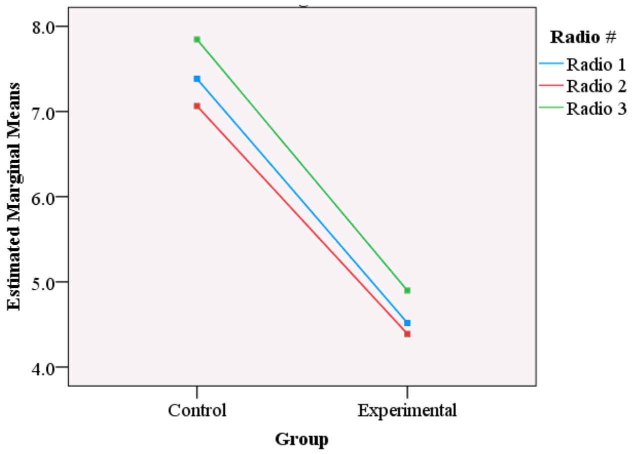

Figure 6. Estimated marginal means of performance for both groups

The results from Figure 6 only demonstrated how the estimated marginal means of the overall performance for all participants in the treatment group compared to the control group. For a post hoc evaluation of the performance within the experimental group, we performed a separate repeated measure analyses for each level within the grouping factor to study the relationship between performance and psychomotor disability.

We analyzed the data with mixed-design ANOVA using a within-subjects factor of disability (cramp, muscle, osteoarthritis, Parkinson's disease, Rheumatoid Arthritis, Tremor) and a between-subject factor of radio (Radio #1, Radio #2, and Radio #3). Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2(2) = 2.681$, $p = .026$). Degrees of freedom were corrected using Huynh-Feldt estimates of sphericity ($\varepsilon = 1.000$) as Greenhouse-Geisser estimates reported an epsilon value above 0.75 ($\varepsilon = .926$) [32]. There were non-significant main effects of disability, $F(2, 66) = 5.566$, $p = .006$ and radio, $F = (1, 33) = 8.129$, $p = .007$. However, the main effects were qualified by a significant interaction between disability and radio, $F(10, 66) = 17.011$, $p < .001$. In Figure 7, we demonstrate how the interaction between disability and radio yielded a significant variation in the estimated marginal means of performance.

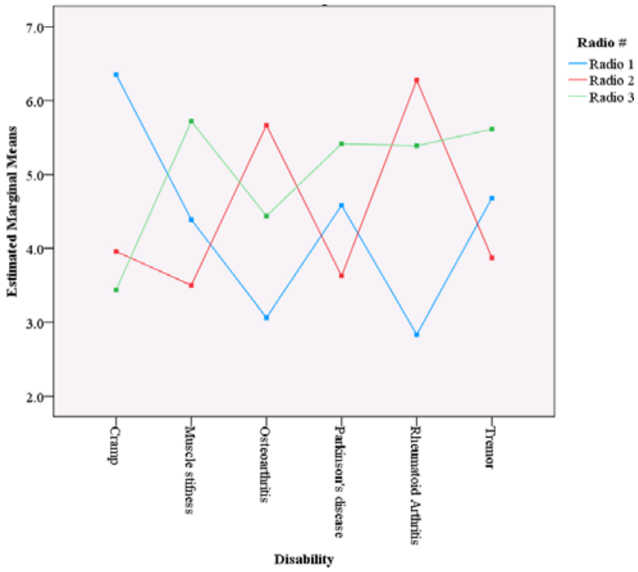

Figure 7. Performance for each disability group across Radio #1-3

Again, the statistical results of this study do not attempt to provide a medical explanation for the performance but instead demonstrates a significant correlation in order to exemplify the need for various interfaces when addressing older adults with psychomotor disabilities. The study only claims the presence of a significant difference in performance but does not provide any solutions.

B. Phase 2: Reflection on psychomotor abilities

The qualitative results generated in the second phase complements the statistical analysis from the first phase by providing additional positive and negative perspectives on the interaction with radios. The qualitative data from the three activities (think-aloud testing of Radio #4, semi-structured demonstrative interview, and input device workshop) were clustered in order to support a holistic analysis of the relationship between psychomotor abilities and challenges that arose during use of the radios. In general, the feedback from the participants provided more depth to our understanding, but also contributed to increasing both the individual and general knowledge amongst the participants. For instance, we clearly saw how the co-exploration with other participants during the input device workshop and demonstrative interviews had an impact on the participants' own self-assessment. 11 out of the 13 participants expressed a positive attitude towards more than one radio as it was usually a minor issue with the design that prevented the interaction. One participant (female, 81) said that there were very small and precise details that prevented her from using the less-favored radios and that she thought she was alone in caring about those details. However, through the three activities of the second phase, participants were exposed to the challenges of other people as well as design alternatives that contributed to learning about alternative interfaces and interaction mechanisms. This mutual learning amongst the participants positively affected their self-esteem and self-assessment as well as the general level of knowledge about the relationship between psychomotor difficulties and their impact on opportunities for interaction.

Since the statistical analysis from the first phase revealed that all participants found purpose with at least one radio, we wanted to further analyze the relationship between psychomotor abilities and concrete tasks. We did not look for a correlation between specific psychomotor disabilities and tasks during this phase, but rather which tasks that introduced the most challenging interaction for our participant group as a whole. From the list of 12 tasks, only two proved to be consistently perceived as challenging. The first common challenging task was the turning of knobs and wheels. Regardless of material, the double-action interaction, i.e., retaining a grip and simultaneously turning the hand, was the most eminent challenge. The following input device workshop confirmed that coarse and jagged knobs and wheels significantly helped on both the grip and resistance. According to the participants, the main challenge was both retaining a firm grip on the knob and simultaneously turning and twisting the knob back and forth. The coarse and jagged input devices helped to interlock the fingers to the knob or wheel and thereby required less pressure on retaining the grip as the hand turned the knob. One participant (male, 78) said that his grip would slip once he started turning his hand as he could not concentrate on maneuvering the fingers and the wrist simultaneously and that the resistance of the jagged edges of the knob supported his concentration. Another important way of counteracting the challenges of turning knobs was to relieve the demand for precision by applying steps with automatic snapping (such as with Radio #1). This helped participants rely less on accuracy and put less pressure on precise movements, something that proved particularly difficult for those experiencing tremor or cramps. Nine participants expressed concerns with turning in general, but with the snapping gesture of Radio #1 only three retained their attitude towards knobs as challenging interfaces.

The second-most challenging tasks was positioning and re-positioning. During the think-aloud testing of Radio #4 similar patterns as seen during the testing of Radio #2 in the first phase emerged. Participants struggled with precise movement of the pods in the air when there were no embodied constraints to restrict involuntary movements and help maneuver or pace the motion. The results from the think-aloud testing of Radio #4 revealed similar issues as with Radio #2 where participants would struggle with the operation due to the raising of the pods midair to initiate the interaction; lifting, suspending, and moving the pods through the air required both jerking and stretching of the arm. Several participants said they were dependent on physical constraints to prevent involuntary movements even during the short duration of the input interaction. Radio #1 and Radio #3 were particularly favored by these participants as the design prevented adverse effects such as dropping pieces or undoing past actions. Even with unintended actions such as sudden spasms or cramps, the design would prevent disruptive consequences. Both Radio #2 and Radio #4 depended on solid cubes or pods to control the radio, and they were partially inoperable to certain participants. These constraints were of particular importance to one female participant (81): *"The sturdiness of the metal bar on Radio #3 neutralizes any involuntary movements I make with its weight and texture, and the friction prevents the wooden ring from sliding away from where I left it"*. Still, there were no significant correlations between the type of psychomotor disability and the degree of need for such physical constraints, but the sample size of 13 participants may not be large enough to identify such patterns. When combined with having to precisely place the pods in a designated area, the combination of strength, flexibility, and accuracy made this task troublesome for many participants. One participant (male, 84) expressed a desire for a snapping mechanisms that would allow the placement or drop to depend less on accuracy similar to the snapping of the knob in Radio #1: *"If it had snapping properties such as found in magnets, it would put less effort on the placement and allow for more concentration of moving the object through the air"*. If we analyze the data from all three activities of the second phase, this issue of positioning was reported by eight participants. However, simple constraints such as the slightly elevated borders encircling the placement zone on Radio #2 made a decisive difference for four of the participants.

The demonstrative interviews also revealed that the participants were highly concerned with progress during the interaction. Most participants stated that they were not directly bothered by using a few attempts to start the radio. The most important factor was whether the failed attempt would reset their progress or not. For instance, turning the knob on Radio #1 in the right direction, even if not reaching the desired channel, would still get the user closer to the goal. A half-finished attempt would allow the user to continue the operation in the next attempt. On the other hand, Radio #2 used cubes that when used unsuccessfully would reset the interaction. We expected participants to be able to hit the top surface at least when not dropping the cube within the designated square, yet only one participant was able to do so. The struggle was tied to the raising of the cube and all incomplete attempts at interaction ended mid-air, and in the best-case scenario, the cube would drop on the table next to the radio. Several participants commented that the limited surface area outside the square area was too narrow to have the cube land on top of the radio in case of missing the square. Thus, it was not failed attempts that would eventually lead to demotivation and frustration; it was not experiencing a sense of progress during the failed attempts. One participant (male, 80) summarized this issue by saying that he did not mind having to repeat gestures to get it right – that was how he already dealt with various equipment in his home – but the moment he felt no progress, he lost interest.

VII. DISCUSSION

A. *Psychomotor disabilities as a shift rather than a loss*

The analysis from the first phase presented in the previous section demonstrates some significant findings. First and foremost, we see that grouping all older adults in one common category cannot be considered scientifically justifiable when their needs, capacities, and performances are so different. To group the participants in one common category is both stigmatizing and improper design practice as it neglects individual needs. Also, we have presented empirical data suggesting that even the specific group of older people suffering from motor deficits in the hands and fingers would highly benefit from designs that paid individual attention to their needs.

At first glance, it might look like Figure 6 illustrates a steady and consistent difference between the control group and the experimental group. However, this was not the case. Irregularities in performance resulted in statistically counteracting mean values, and glancing at Figure 6 one may wrongfully conclude that the older participants yielded a seemingly equal performance score for each radio regardless of their motor capacities. However, as presented in the secondary analysis of the relationship between disease and performance (illustrated in Figure 7), we see performance scores with high fluctuation within each group. We can confirm this by looking at the statistical analysis which indicated a significant interaction between disability and radio ($p < .001$).

One way of understanding this phenomenon is to look at average performance score for each group. The participants who suffered from trembling serve as a good illustration. This group, which accounted for a third of the participants in the experimental group, had the lowest performance score on Radio #2 ($M = 4.19$, $SD = 0.40$), an intermediate performance score on Radio #1 ($M = 05.07$, $SD = 1.57$), and the highest on Radio #3 ($M = 6.08$, $SD = 0.98$). These results can be explained by the different types and various symptoms of tremor. Participants reported issues with intention tremor that could affect their aim, specific tremor which influenced goal-oriented action), as well as general stressing tremor. As Radio #2 required participants to raise a cube in midair and place it within a designated area, it was difficult for several participants to operate this radio. With more degrees of freedom compared with the other two radios, there was more room for both intentional and deliberate errors. This group performed best on Radio # 3 as involuntary movements would not give adverse effect or hinder progress in solving the task.

A similar pattern can be seen in the group of participants who suffered from Rheumatoid Arthritis. They reported challenges with swelling, decreased sensitivity and reduced mobility, which resulted in problems with the interface of Radio# 1 ($M = 2.83$, $SD = 0.99$). The reduction in sensitivity, in particular, would mean that they struggled more with sensing moving, clicking, and snapping feedback from the radio. However, they delivered a good average performance score for Radio # 2 ($M = 6.28$, $SD = 1.74$), suggesting that they still had the capacity for interaction.

Thus, loss or reduction in motor capacities does not an automatically reduce or deprive our interaction opportunities; it mainly shifts them. All four of our radios were developed to allow people with motor impairments in their hands and fingers to still use these limbs for interaction. Moreover, our results suggest that they are highly capable of doing so if presented the right interface. In their studies of differences in pointing movements between older and younger users, [17] argues that older people maintain the use of residual sensory information (vision and proprioception) and can achieve similar precision levels as younger users. However, the radios in our study do not need to be operated by hands and fingers. There are also opportunities that explore new bodily uses and configurations. In certain context, radios are naturally operated through different interaction mechanisms, e.g., in cars. Prior studies have also demonstrated interaction opportunities for people with motor disabilities by the use of other bodily capacities. For instance, [33] uses head gesture recognition for wheelchair control for older adults who have Parkinson's disease and other restrictions in limb movement. The authors of [34] study wrist rotation as input mechanisms for mobile devices, and suggest that both hands-free and eyes-free interaction techniques would be feasible with further research. The research of [35] uses a voice-driven drawing application to include users with motor impairments.

We should never exclude any people as potential users just because their capacities prevent them from using a given interface. Incompetence or inability in use should not be tied to technologies, but instead, be a use dimension related to the specific interaction mechanisms that the technology provides. Radio might be considered one piece of technology, but there are limitless opportunities when it comes to the way it is presented to the user. The results in this paper have demonstrated that people can re-establish meaningful relationships with technology by shifting the way of presentation.

B. *Designing with psychomotor abilities in mind*

The second phase provided insight into how we should address the matter of psychomotor challenges both during the design process and in the design artifact. The self-assessment amongst the participants strongly depended on how the participants were given an opportunity to explore and reflect upon their own capacities; experiencing design alternatives as simple or demanding helped participants express and explain their perspectives during all three activities. Presenting participants with a wide selection of alternatives has previously helped us to support decision-making and mutual learning the during design processes [31]. The input device workshop clearly helped participants obtain an insight into own capacities and preferences that would not have been possible without actually interacting with physical prototypes and objects. Some aspects of psychomotor abilities, e.g., tactics or response-ability [29], are hard for participants to imagine and reflecting upon these capacities supported by physical props to enhance the exploration clearly contributed to a more insightful and honest feedback. During the input device workshop, the participants in both groups unanimously agreed that amongst the alternatives they were exploring they could all find several components that they would be able to operate. The different components exploited material properties such as texture, size, shape, and color to provide various ways of providing input. It was important for the participants' self-esteem to revisit various modes of input and thereby reminding themselves of their capacities despite their psychomotor challenges. This also motivated the participants to talk more positively about their own bodily capacities and reflect about their psychomotor challenges with a more optimistic and salutogenic outlook. While we did not investigate gender-based differences with regards to self-assessment of psychomotor abilities – something [28] argued could yield differences between genders – we believe the input device workshop helped participants realize both own capacities and limitations and adjust their self-estimates accordingly. In future studies, it would be interesting to further investigate the correlation between participants' self-assessment own psychomotor abilities and their performance by the use of standardized models such as those presented in [28].

We also registered how participants would successfully perform tasks that required a single type of psychomotor ability, but would struggle when the tasks introduced multiple actions depending on several types of abilities. The trouble of performing simultaneous actions has been previously addressed by [6], and the issue became particularly evident during the second phase where participants explained how both turning and positioning required simultaneous rather than sequential actions and put more pressure on their abilities. The results from the second phase suggest that constraining design, e.g., the aluminum bar in Radio #3 or the volume slider in Radio #4, helps reduce the number of simultaneous actions required to perform a task. While several participants favored radio #2 and #4, the elevated position of the placement area on top of both radios became a challenge when the placement also required accuracy. This issue was further enhanced by the level of difficulty of the individual tasks, in particular, accuracy. Preciseness in gestures and movements was considered one of the most isolated challenging issues as the tension, flexibility, and endurance required for precise maneuvering usually involved a high level of physical effort and concentration. This observation is supported by the registered patterns presented in [12], where it is claimed that accuracy levels are only kept constant when contributing more time. Thus, we clearly saw value in understanding and addressing the psychomotor capacities, both individually and combined, when shaping the interface of the radio. In particular, physical and embodied constraint as well as guides for movement reduced the simultaneous actions required from the participants and eased the physical demand from the user.

Another way of reducing the tension from simultaneous actions was to support psychomotor capacities with cues. In particular, participants suffering from reduced mobility and sensitivity emphasized the importance of visual cues to support tactile or haptic feedback. Radio #4 did not provide as clear borders for the placement zone as Radio #2 and certain participants were insecure about their own precision once the pod was placed as they could not feel the pod dropping into the shallow circular pit. One participant said that just increasing the depth of the circular area of Radio #4 would have provided better feedback from him as the physical constraints would be enforced as well as help provide visual feedback of correct placement. In our empirical context, we have previously seen how material characteristics can not only influence how the participant understand the interaction but by its properties, e.g., surface, shape, and color, provide cues on how to properly interact with technology [21, 26].

C. *Extending and re-establishing purposeful interactions*

It is important to note that none of the three radios used in the first phase were perceived as uniformly better than the rest. Each radio would yield good scores with one or more groups, but there was always another group that would struggle with the same interface. This supports our claim that radios designed for a specific group of people, and with features that may even fully compensate for the motor deficit, will still not necessarily work for everyone. Hence, the results of this study demonstrate not only the need but also the possibility, to make individual adjustments in the design of interfaces. Even though we developed four radios, they all utilized nearly identical hardware, and the basic electronic components are the same in all four radios. The back of the three radios Radio #1-3 and how their hardware is enclosed in similar casement taking up roughly the same size is demonstrated in Figure 8. They were developed in four independent processes focusing on various psychomotor challenges, yet we see that only the packaging, i.e., the "outer shell" enclosing technology, is changed. By designing four different interfaces, we have shown that it is possible to re-enable an entire group of older adults who would otherwise have to abandon interaction with radios. We achieved this while letting them continue to use their hands and fingers, something which is not a requirement for successful interaction. If we expand the design area to include all other bodily capacities, the potential to re-establish purposeful interaction would be even greater, and the chance is simultaneously greater for technology to remain meaningful longer, even when living through a decline in psychomotor capacities. To offer users a variety of interfaces on top of the technology also provides users the ability to customize the interaction to their capacity levels, even if they were to discover at some point that some of their motor skills develop in a positive sense. Adapting to skill levels is encouraged by [29]. It would also open up more room to address changes in movements, actions and bodily configurations as psychomotor skills among user group changed. The authors of [7] suggest that there is a natural discontinuation in slow movements among older people. This is also supported by [6] who suggest that older participants depend on interfaces that allow for more sub-movements in interaction. In general, it is considered reasonable to spend more time on interface adaptations since the majority of prior research only studied two-factor analysis of the interaction and psychomotor capacity in a context where other conditions such as frequency of use and expertise could have had an impact on the interaction [10].

Figure 8. The back of the three radios Radio #1-3

In our empirical context, this idea of introducing multiple interfaces is of particular importance as Norway is facing an infrastructural change where all radios are switching from FM broadcasting to digital audio broadcasting (DAB). This will render all current FM radios unusable as of 2017. People with older radios are forced to buy new devices where the interaction may depend on users properly learning and understanding new interfaces, new terminologies, new frequencies and new mechanisms. However, prior research simultaneously suggests that elderly people are less willing to modify current strategies or adapt new strategies [6, 36]. This forced transition gives us a golden opportunity to introduce a variety of interaction mechanisms that can be incorporated into routines and habits while people are relatively able-bodied and only shows early symptoms. By doing so, the technology could potentially remain with them even if they were to enter a downward phase with reduction of capacities. If someone should not develop symptoms consistent with the expectations, having incorporated these new interaction mechanisms may still have a positive effect as it is often the underlying factors that are to be blamed for reduction of psychomotor skills, e.g., in the performance of tasks aiming [13].

Another important factor is the degree of stigmatization associated with use. Technology tailor-made for a particular group of people often succumbs to design choices so distinctive that other people can interpret the intended users their weaknesses just from the design itself. Our participants claimed that all four radios, but, in particular, Radio #3 and Radio #4, had an appealingly aesthetic look that did not suggest being specifically designed for the target audience. The design did not emit the stigmatizing radiance often found in technology tailored for the elderly [5]. Early exposure to interfaces that can have a secondary function later will also allow older users to make acquaintances with interaction mechanisms that have not yet become vital for their use. This would mean fewer chances of experiencing the design and interface as stigmatizing, even though it sometime in the future may become the very interaction mechanism allowing interaction; the interaction is associated with routines and habits rather than to imposed solutions.

This discussion of avoiding stigmatizing design further aligns with the idea of universal design. Design tailored for specific disabilities or illnesses does not exclude people without disabilities from using them. On the contrary, we found that the design of our four radios, and, in particular, Radio #3, appealed to participants and stakeholders that were not in the user group such as family members, employees at the care home, and even our self as designers. In future research, it would be interesting to investigate this aspect of the design further. While our results does not provide any significant evidence of one radio fully re-establishing interaction for all types of psychomotor disabilities, we did see examples of radios elevating the interaction performance to the level of the control group for multiple types of disabilities and illness (as demonstrated with Radio #1 and Radio #2 in Figure 7). It is therefore not unreasonable for further research on this topic to generate designs that can reach even more people and help users achieve even better performance scores. Nevertheless, the aesthetics of the four radios demonstrate the important underlying idea that design tailored for a specific user group can very well be fully usable and appealing to everyone. There is no reason that design for older adults cannot be design for all.

VIII. Conclusion

This paper has attempted to bring attention to the richness of psychomotor capacities that still inhabits aging bodies. Despite certain capacities declining or disappearing, a better understanding of both the psychomotor abilities and disabilities of the participants can help inform the design and thereby re-establish and prolong interaction. We have used four radios co-developed with old people to demonstrate how people unable to operate commercial radios have not only rediscovered interaction opportunities but simultaneously achieved levels of performance comparable to people operating commercial radios. We have also facelifted activities that has generated important knowledge about what types of interfaces and interaction mechanisms that proved the most difficult and how we can address those issues in the design of radios. A total of 65 participants were involved over four years in two phases to help gather the data used in this paper. Our findings are limited to our empirical context but still demonstrate on a broader scale how the body inhabits capacities that when understood and acknowledged properly can help users continue to interact with technology despite experiencing psychomotor disabilities.

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