Rethinking the Fusion of Technology and Clinical Practices in Functional Behavior Analysis for the Elderly

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Abstract. Functional assessment is the test of the ability of a person to perform basic self-care activities that are instrumental for living safely and independently in a home. Gerontology classifies these self-care activities as, Activities of Daily Living(ADL). There exist many clinical and systems measures for performing functional assessment. This paper critically reviews the state of art in these assessments. This paper also talks about the disconnect between the clinical and the technological measures. It also discusses future directions to establish a practical and objective method of conducting functional assessments.

1 Introduction

New advances in health care, and improved quality of life have increased the average life expectancy of a person. As a result, people are aging longer, and the elderly (aged 65 and above) are becoming a major segment of the population. While the projected population of elderly is expected to double from 2000 to 2020 from about 11% to 22% [1], the number of health care professionals is only expected to increase by 10% [2]. In the next five years, the gap between the population and care will increase to the extent that it will lead to a high cost of health care services. As a result, there is a high emphasis to support the concept of *aging-in-place*, where the elderly are encouraged to live in their homes for as long as it is possible. However, aging-in-place needs adequate supervision and support to ensure the safety of the elderly in their residence.

The safety of an elderly person in a home is highly correlated to their ability to perform basic functions that allow them to socialize, work, etc. These fundamental self-care activities have been labeled *Activities of Daily Living*, or ADLs. The analysis of a person's ability to perform ADLs is referred to as *functional behavior analysis* or *functional assessment*. Many elderly people experience problems in ADLs because of illnesses or health-related disabilities. For example, people suffering from heart failure or lung infections may lack the physical stamina to manage household tasks like cleaning, cooking, and laundry on their own. A functional assessment can identify if an elderly person needs outside help, such as home care, moving to an assisted living facility, etc.

Designing a functional assessment requires making two main decisions: what activities need to be examined, and what is the scale on which each activity

needs to be rated. There have been studies conducted by clinical researchers, as well as systems researchers, to develop such an assessment tool. Clinical researchers have conducted large-scale population studies and proposed multiple instruments of functional assessment. Systems researchers, working in the *Activity Recognition* community, have also proposed a technological methods to automatically sense the decline in functional abilities of the elderly. In this paper, we critically review the state of the art in ADL assessment using clinical practices as well as technological measures. We discuss a number of limitations in the these measures, to make a case for these two communities to address the challenges jointly.

A review of the various clinical instruments of functional assessment reveals the strengths and limitations of their proposed methods. These instruments are designed as self-reports or interview style questionnaires. In the US, each state has its own instrument derived from the numerous clinical scales that exist. Once an elder checks into a formal service system, such as an assisted living facility, they start undergoing a mandated semi-annual/annual functional health assessment. The clinical instruments do not focus on the dormant abilities of a person by asking questions such as 'Can you bathe?'. This is because the answer may be unrelated to the person's actual performance of the activity. Instead, they assess the ADLs that are actually performed by a person by asking questions such as, 'Do you bathe?'. Each ADL on the list is rated in different degrees of the person's ability to perform it - ranging from 'Able to perform independently', to 'Requires partial assistance', to 'Requires total assistance'. In spite of the proliferance of clinical instruments, there are many limitations in this body of methods. One such limitation is the non-uniformity of the ADLs monitored across the different instruments. The non-uniformity can result in a person being assessed differently across states within the same country. Also, the human-in-the-loop factor imposes limitations on the scalability of these methods with the increasing elderly population.

Technology is a great way to address the issues of non-uniformity and scalability present in the clinical assessment methods. This is because once setup, the cost of making additional measurements is negligible. Systems sensing methods are mainly based on the heuristic that if we can detect when a person performs a certain ADL, we can monitor the decline in the frequency of performance of the ADL and conclude that the person is losing the ability to perform that ADL. Another heuristic monitors the changes in fine-grained usage pattern of an object to determine loss of functional ability.

In either of the heuristics, systems are expected to be able to monitor the object usage in homes using sensors. Systems researchers have explored the use of various sensing modalities such as accelerometers, reed switch sensors, cameras, microphones etc., in order to sense various ADLs. Some systems use just a single wearable device, while others derive their inference from wearable devices worn at multiple locations. Some systems depend on instrumentation of all the salient objects in a home, while others focus on using single point sensing of water and electricity mains to determine the object usage based ADLs in the home. One

of the limitations in the systems based methods is the lack of clinical validation of the heuristics the systems are based on. Its unclear if this type of monitoring can be used to conclusively determine any deterioration of functional abilities.

This rest of this paper is organized in the following manner: Section 2 describes the need to monitor functional capability at an ADL granularity. Section 3 critically reviews the clinical methods of ADL assessment. Section 4 critically reviews the technological solutions of ADL assessment. Section 5 reviews future work and directions in this domain.

2 Background

In 1984, the WHO Scientific Group on the Epidemiology of Aging reported that the ability to function independently was a good indicator of the state of health of the elderly [4]. Since then, many clinical studies have been conducted to determine how to assess functional ability. The outcomes of some of these studies have been tools or instruments of functional assessment. These instruments take into consideration the ability to perform certain tasks crucial to daily life [17, 9, 10], which are referred to as Activities of Daily Living or ADLs.

The two main subcategories of ADLs are Basic ADLs, such as 'Dressing' which refer to the ability of a person to live within a home, and Instrumental ADLs such as 'Driving', which refer to a person's ability to live within a community. However, within these sub categories, each clinical scale has its own set of labels, some of which may specify activities very specifically such as 'brushing teeth', and others just refer to broad categories, such as 'grooming'. The instruments of functional assessment intend to track the ability to perform certain basic and instrumental ADLs.

Changes in functional abilities of an elder are usually the manifestation of the changes in the cognitive and physical abilities of the elderly, such as changes in how well elders are able to perform task such as meal preparation, grooming, ease of transferring between bed and chair etc. Since these tasks are performed in a routine manner by the individuals on a regular basis, they may not notice the changes in their own abilities. Therefore it becomes important to monitor the functional status of an individual.

This is done at an ADL level granularity for many reasons. Firstly, knowing what ADLs an elder needs help with, determines the type of assistance they require. For example, if someone needs help with bathing, they can pay for a weekly home care service. But if someone needs help with transferring from bed to chair and vice-versa, they may need someone to assist them everyday. These decisions are crucial as they determine the expenses of recruiting care. Secondly, monitoring all ADLs can show if there is a functional decline due to normal aging or a medical problem. This is because the after-effects of a major surgery or a medical condition may affect certain functional abilities only.

There are federal and state funded programs in the US that provide free care to the elderly using Medicare and Medicaid [3]. Every individual enrolled in this care service is assessed not only medically but also functionally. Functional be-

havior analysis is important in these programs so that the limited care resources are utilized optimally among the elderly.

3 Survey of Clinical Methods of ADL Assessment

There are broadly two types of clinical assessments that can be performed to determine an elder's ADL functions [5]. One type of assessment focusses on what ADLs an elderly person currently does and how they do it. This type of assessment is referred to as *Task Frequency*. The other type of assessment measures the degree of how well an elder can perform each ADL, which referred to as *Task Ability*.

Task frequency, is the most common type of elderly functional assessment. In this type of assessment, a scale or an instrument is used to to test the person on a pre-defined set of ADLs. The scales are usually easy to administer and score, and are typically designed to be completed within an hour. Their formats may vary from a self-assessment form to an interview with an human assessor. The set of ADLs present in the scale is empirically identified by the researchers proposing the assessment. For each label of ADL, the assessor marks a score according to the scoring function specified by the scale. For example, for the ADL 'Walking', a person can be scored from 0-6, where 0 is 'no assistance required', 1 is 'uses some mechanical help', 2 is 'uses human supervision', 3 is 'uses human assistance', 4 is 'uses mechanical assistance and human supervision', 5 is 'uses human and mechanical assistance' and, 6 is 'cannot perform this ADL' [6].

There are many different indexes for measuring an elder's ability to live independently. Some of them are the Katz Index of Independence in Activities of Daily Living [9], The Lawton Instrumental Activities of Daily Living [10], The Barthel Activities of Daily Living Index [11], Bristol Activities of Daily Living Scale [12], The Bayer Activities of Daily Living Scale [13], The Frenchay Activities Index [14], Nottingham Extended Activities of Daily Living [15], TMIG Index of Competence [16], Klein-Bell Activities of Daily Living Scale [17], Myasthenia Gravis Activities of Daily Living Profile [18], Guttman health scale for the aged [19] and Older Americans Resources and Services (OARS) Activities of Daily Living scale [20]. In addition to these, in the US, the state governments have their own instruments derived from existing clinical instruments. For example, the Uniform Assessment Instrument is used in Virginia [6] and the Hospital and Community-Patient Review Instrument is used in New York [7]. Once an elder checks into any formal service system, they are monitored using these state mandated instruments on a annual/bi-annual basis.

Different instruments can use different labels to refer to the same activity or finer aspects of the same activity. For example, [12] refers to the act of using the toilet as 'Elimination', whereas [6] refers to the same activity as 'Continence', and further sub-categorizes it into 'Bowel' and 'Bladder'. Some ADL labels are present in many instruments, such as 'Bathing'. While other labels such as 'Write Letters' are present in only one or two instruments [15]. Figure 1 shows a tree map of the various ADLs present in the twelve indexes. We can see that some

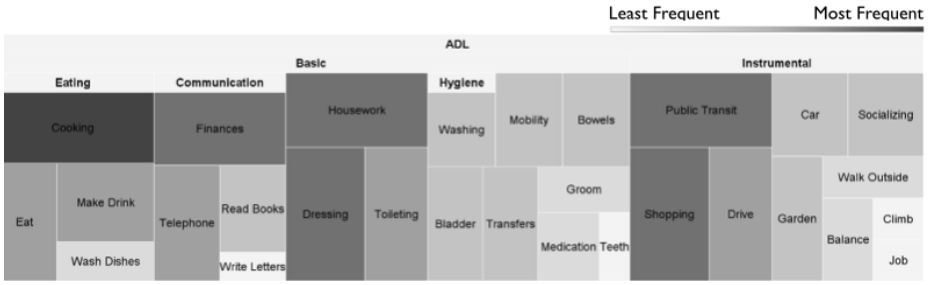

Fig. 1. A tree map of all the ADLs listed in different interments of ADL assessment reveals that there is a varied emphasis on different activities that are considered most basic for self-care. While some activities such as 'Dressing' and 'Bathing' are common to many instruments, other activities such as 'Write Letters' are more niche to a certain instruments

ADL labels are more niche, while others are more common across the different measures.

The task frequency type of assessments are easy to conduct. Therefore, the state can mandate it in the entire formal elder care service sector. On the other hand, task ability type of assessments are more niche and currently mandated by government in nursing facilities only. This type of assessment is not easy to conduct, and requires an occupational therapist to administer them. To conduct this assessment, the therapist may interview the person, in addition to using observation to rate the ADL abilities. Some examples of such assessments are the Melville-Nelson Evaluation System [21] and the Performance Assessment of Self-Care Skills (PASS) [22]. In this type of instrument, a compound task is broken down into atomic tasks. An elder is then asked to perform the compound task, and every atomic task is rated for independence, safety and adequacy. For example, the task of 'Telephone Use' for using a cordless phone and automated pharmacy is further sub-divided into atomic tasks such as: 'Reads handout from therapist and selects a pharmacy', 'Locates telephone', 'Dials pharmacy number', 'Positions telephone receiver for call', 'Navigates phone menu choices', 'Ends call appropriately' and 'Reports information' [5].

Critique: Despite an over abundance of scales to measure ADL function, the field of elder assessment largely remains subjective and therefore not scalable with the increasing population of elderly. Future work in developing the scales could benefit from considering the following:

– *Creating a dictionary of ADL labels*
One of the main differences between the instruments of functional assessment is the choice of ADL labels. The ADLs are different not only in the type of activities that they represent but also the granularity of each activity type that is monitored. The inconsistency in what needs to be monitored is confusing, because there is no obvious basis on which labels should be selected for any elder. Every state in US has its own set of ADLs, which

is then applied uniformly to all elderly within the state. So while elders are monitored differently and therefore possibly treated differently in each state, individuals having different lifestyles, cultures, and socio-economical backgrounds within the same state are monitored with the same set of ADLs. A dictionary of ADLs would help create have a unique label for every activity. It can also help create labels that represent different activities performed in different lifestyles. For example, there may be a special interest in monitoring 'Making Tea' in Japan. In fact there are internet kettles sold in Japan which intend to monitor how often an elder is making tea, and send this across to their children [23]. For the children, this simple action can provide a measure of the elder's well being.

- *Elder's value of activity*
  All the scales of ADL have one thing in common: they each propose a fixed set of ADLs that they deem are important for independent living. As such this poses a problem when the scales are used for the purpose of determining if an elder needs to be moved from the community to an institution and what care facilities would the elder require at the institution. However, a big factor of the decision to institutionalize, depends on the perceived value of an activity from an elder's standpoint. For example, many of the ADL indexes enlist 'Cooking' as a primary function that the elder should be able to perform. However, a person may not like to cook, or even know how to cook. And in spite of not knowing how to cook, can lead a healthy life, because they have either someone cooking for them or order food from outside.

- *Valuing practicality with reliability*
  An index may have many detailed activities in it. A detailed set of activities in an index, attempts to capture the full details of an elder's functions. However, it also increases the number of activities that need to be assessed. Fewer activities in a scale however make it more practical, since it minimizes the assessment effort. It could be helpful if we could identify a few compound activities that encapsulate a large number of motor functions to have a good marriage of practicality with reliability.

- *Measurability using technology*
  When the scales were developed, they focussed on activities that could be assessed using interviews. The biggest challenge with this method, is that it requires a person to visit the elderly, and assess them. This is a fairly expensive method, especially when conducted frequently. Having activities that are measurable using technology has many advantages. The activities can be monitored more cheaply. frequently and most importantly in an objective manner.

4 Survey of Systems Methods of ADL Assessment

From a technological and automatic sensing standpoint, the field of determining the activities of daily living (ADLs) aligns strongly with the field of 'Activity Recognition'. We selected top 25 of the well cited research papers in activity recognition returned by Google Scholar [24], eliminating survey type papers [25]-[50]. Our survey also confirms that one of the most common motivations for research in this field is the need to detect the decline in functional and cognitive abilities in the elderly, or eldercare.

The use of a technological method to assess functional behavior can be justified by three main reasons: 1. provides an objective measure of ADLs, 2. it is scalable because of the potential of sensing being cheap in future, 3. it can be used to assess an elder more frequently mainly because there are no additional costs per measurement.

The work in this field broadly relies on two types of heuristics to perform functional assessment:
1. Task frequency heuristic - The decline in the frequency of an ADL performance is indicative of decline in functional and/or cognitive ability.
2. Task ability heuristic - Changes in the time and pattern of performing atomic tasks to complete a single compound task, is indicative of decline in functional and/or cognitive ability.

Table 1. Survey of technology used in different systems

Paper	**Activities**	**Type of Sensors Used**
[27], [29], [31], [39], [40]	Ambulation	Tri/bi-axial accelerometers on body
[30], [36]		Smartphone accelerometer
[37], [44]		Cameras in home
[28], [38]	Basic ADLs	State sensors on objects in homes
[32], [45]		State, temperature, humidity sensors on home objects
[33], [35], [42]		Cameras in Home
[48], [41], [43]		RFID gloves and tagged objects
[49]		Cameras+RFID tagged objects

The solutions proposed by the researcher can be classified into various sensing modalities, as shown in Table 1. Some sensing modalities are more typically used for ambulation related ADLs such as walking, running, climbing stairs etc., such as bi/tri-axial accelerometers worn in a device on the body. Over time, researchers have improved the number of activities that can be detected using fewer number of wearable accelerometer devices on the body with more precision. The use of other modalities such as RFID tagging is more commonly used for detecting basic ADLs such as cooking, making coffee etc.

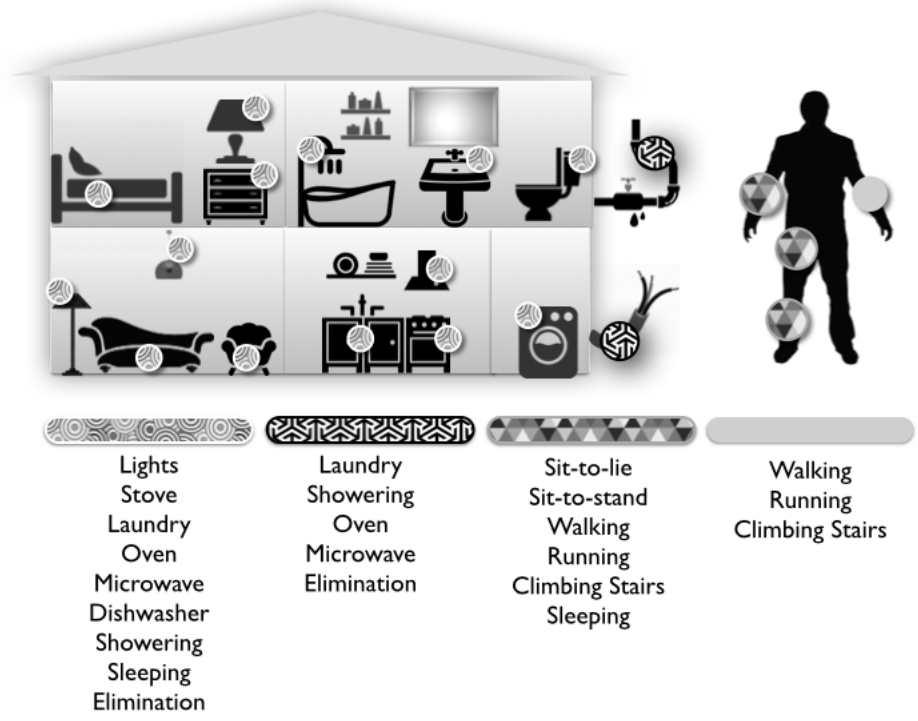

Fig. 2. While more number of sensors can detect a richer set of ADLs, it is more practical in terms of cost and maintenance to have systems that can infer ADLs from fewer sensing points

In the current state of art, the sensor based data is expected to be useful for providing feedback to the elder for improving self-awareness on how his/her individual abilities might be changing over time. This type of data is also expected to be useful to a gerontologist to help diagnose the functional abilities of an elder, although it isn't very clear in what format would the data help them with a diagnosis [5].

Based on where the sensor is located, the main body of sensing modalities in this field can be classified in the following way:
1. Body Wearable Device- Single/Multiple locations [25, 31, 27]
2. Instrumented Home - Mains/Per-Fixture Monitoring [28, 45–47]
3. Combination of Body Wearable Device/Instrumented Home [48–50]

Figure 2 shows a list of ADLs that can be sensed using these sensing modalities. Since there is no single/standard instrument of ADL assessment, researchers in the field of activity recognition select and focus on ADLs labels of their own choosing. While some researchers have created sensing solutions focusing on a wide variety of ambulation related ADLs such as walking and running, others

focus on the basic ADLs that require the use of appliances and water fixtures in the home, such as bathing and cooking. In general, a review of the literature suggests that instrumenting the person is the most common method of detecting ambulation, while instrumenting the home appliances, and/or the electric and water mains is the most common method of detecting basic ADLs.

Instrumenting multiple points usually gives much detailed information about the activities. For example, single point sensing of electricity of a home cannot infer the source small electrical events such as 'Switching on a light', and single wearable device cannot differentiate between different modes of a rested body such as lying down vs. sitting. When there are multiple people sharing the same space, the use of a wearable device and the fixtures in the home is one of the common ways to detect who is using the fixture. Most of the ADL detections are based on the Task Frequency heuristic. These systems detect every time that a person performs a certain ADL and construct a timeline of the frequency with which an elder performs that ADL. There is a smaller subset of researchers in this community who focus on detecting ADL with an emphasis on the Task Ability heuristic. In this type of sensing, typical objects used in ADL such as the coffee machine, are highly instrumented and each atomic step in the object usage is monitored for deviations in pattern of typical usage.

Critique:While technology is a good solution that can scale with the increasing population of the elderly, it has a few challenges that prevent it from being applied for functional assessment in the current state of the art.

- *Packaged Solution*
  The sensing solutions for detecting different ADLs are varied. Some use RFID tagged objects and wearable gloves to detect certain activities such as cooking food, while others use multiple sensors attached to the body to determine when a person is sitting vs. lying down. One of the problems with the current state of art in activity recognition is the fact that every system configuration is different. There is no principle to pack the various sensing modalities into a single solution. A principle of integrating the multiple technological needs to be identified, where all the activity recognition solutions use a unified framework.

- *End-to-end solutions*
  Until now, most of the research focussed on getting the sensing right. For example, vision based activity recognition can identify the low level behaviors of people and determine what activity they are doing. The main challenge is that this system needs to be able work out of the box in different unstructured environments, subject to different constraints. For example in a vision based system, it should have the ability to work in low light conditions, have a coverage of the living space, ensure privacy in homes, etc. While a basic installation cost may be acceptable to elders, tasks that require major configurations and precise calibration, increase the installation costs and may prove to be a deterrent in the widespread adoption by elders.

– *Empirical evaluation*
Almost all of the activity recognition research papers cite elderly monitoring as a compelling motivation, and yet few of them actually test their system on the elderly. Understandably, the biggest challenge to elderly testing is the recruitment of elderly participants. Elderly participation is also a challenge since many times the systems are chunky prototypes, and the experiments conducted are controlled in nature. Experiments having an in-situ component with wearables that can actually be worn comfortably by the elderly are important to ensure that a solution has been validated for the correct end user. Experimenting with the researchers can often remove the noisy signal characteristics that can be present when an elder uses the system. For example, a wearable device with accelerometer will probably register a lot of shakiness when used by a person suffering from Parkinson's.

– *Consideration of Multi-Occupants*
According to a recent statistic, almost two-thirds of the elderly population in US actually live in a multi-resident home [1]. This means that infrastructure-mediated sensing paradigms such as Non-Intrusive Load Monitoring (NILM) systems need to consider that the activities sensed based on the use of different objects in the home can be attributed to multiple individuals. Therefore, any system that purely detects activities from an object-use stand point also needs to be able to integrate a method of determining which person actually used the object.

– *Capture competence of activity*
The paradigm of activity recognition should not be restricted to sensing activities alone. An important aspect informing the state of health of the elderly is their competence in performing the activity. By simply capturing the fine-grained performance of an activity such as cooking, we cannot know of behavior such as spills during cooking, which is important in ascertaining if the elder is in danger of a potential accident while performing the activity.

5 Discussion

One of the biggest challenges in future of functional behavioral analysis of the elderly will be the ability to scale up to the population increase. By 2050, there are expected to be 2 billion adults in the world, aged 65 and above [1]. The current means of functional assessment is highly dependent on experts such as gerontologists, care givers and occupational therapists. Technology, especially cheap sensing technology, is promising in that it is widely pervading the homes and lives of people. There are various modalities of sensors that can provide rich information about the activities that people are performing. The concept of connected homes along with the advent of Bluetooth Smart, has made the appliance usage information more accessible. More homes are getting smart electric meters, making the mains information easily available as well. As appliances get old

and are replaced with the appliances supporting these new sensing technology, the cost of instrumenting the fixtures in homes becomes negligible. Wearable gadgets are already available commercially. These gadgets have a wide variety of sensors on board, such as Inertial Measurement Unit, Wi-fi, GPS, microphone etc., which are used the activity recognition community.

Table 2. Limitations in the state of the art in functional behavior assessment methods

Clinical Methods	Technological Methods
Dictionary of ADL labels Elders value of activity Valuing practicality with reliability Measurability using technology	Packaged Solution End-to-end solutions Empirical evaluation Consideration of Multi-Occupants Capture competence of activity

While there is sufficient evidence that supports the idea that eventually in future, obtaining sensing information for elderly monitoring will be available very cheaply and widely, there are other things that we need to consider to make sure we are going on the right track as a community. This is because the two main heuristics used in this community aren't validated in clinical studies. The disconnect between the clinical research community and the technological research community, and the limitations in the current state of art (Table 2) need to be addressed before we can claim that technology can detect changes in the functional behavior in the elderly. Interviews with gerontologists and occupational therapists [5] have revealed that they do not understand how to interpret the quantitative nature of the data yet. One of the main reasons for this is that it is not clear when to treat changes in pattern as an anomaly, that indicates functional decline, or a conscious change in person's lifestyle. A system that generates a large number of false alarms is unlikely to be adopted by the masses.

While the aim of this paper is not to undermine the contributions of activity recognition in elder monitoring, it seems important that there be an explicit declaration in the community that, at this point, claiming that a system can detect functional decline in the elderly using the existing heuristics, is likely to be over ambitious. There is danger of a *snowball effect*: a large number of papers claiming to perform the functional analysis by simply detecting ADLs, might influence other researchers into believing that this is a clinically validated fact.

One of the main reasons why this major disconnect exists, is because the methods used by the clinicians to determine functional abilities were not designed to be objectively measured by sensing technology. It seems like its time for both these communities construct a dialogue around these issues and develop some guidelines, so that together they can design methods can meet the needs of the future more efficiently. New alternative solutions can be designed. For example, the use of systems like Apple's ResearchKit [51] can be used to determine the efficacy of a sensing solution over a wide range of population.

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