Development of an ontology to characterize mental functioning

Maryanne J. Sacco, Guy Divita & Elizabeth Rasch

Published online: 13 Sep 2023.

Submit your article to this journal ⬚

View related articles ⬚

View Crossmark data ⬚

Taylor & Francis
Taylor & Francis Group

Check for updates

COMMENT

Development of an ontology to characterize mental functioning

Maryanne J. Sacco, Guy Divita and Elizabeth Rasch

Rehabilitation Medicine Department, Epidemiology and Biostatistics Section, National Institutes of Health, Clinical Center, Bethesda, MD, USA

ABSTRACT

Purpose of the article: This article describes a conceptual and methodological approach to integrating functional information into an ontology to categorize mental functioning, which to date is an under-developed area of classification, and supports our work with the United States (U.S.) Social Security Administration (SSA).

Design and Methodological procedures: Conceptualizing and defining mental functioning was paramount to develop natural language processing (NLP) tools to support our use case. The International Classification of Functioning, Disability, and Health (ICF) was the framework used to conceptualize mental functioning at the activities and participation level in clinical records. To address challenges that arose when applying the ICF as to what should or should not be classified as mental functioning, a mental functioning domain ontology was developed that rearranged, reclassified and incorporated all ICF key components, concepts, classifications, and their definitions.

Conclusions: Challenges emerged in the extent to which we could directly align components in the ICF into an applied ontology of mental functioning. These conceptual challenges required rearrangement of ICF components to adequately support our use case within the social security disability determination process. Findings also have implications to support future NLP efforts for behavioral health outcomes and policy research.

➤ **IMPLICATIONS FOR REHABILITATION**

- Mental functioning in everyday life is an important area of inquiry from the perspectives of public health, health policy, healthcare, and overall individual level health and well-being.
- A domain ontology of mental functioning that defines concepts and their relationships, and provides a common terminology with definitions, would enable interdisciplinary communication, research, and collaboration.
- A clearer conceptual model of mental functioning can improve the development of software that can identify, codify, and organize mental functioning information within clinical records into data that can be analyzed.
- The International Classification of Functioning, Disability and Health was utilized to conceptualize mental functioning and to guide the development of a proposed domain ontology of mental functioning.

Introduction

The International Classification of Functioning, Disability and Health (ICF) [1] was developed as a common language (taxonomy) and classification system to characterize the components of functioning as the consequence of diseases. Specifically, the ICF represents a way in which underlying health conditions and environment interact to reflect an individual's ability to participate in daily life activities, such as work. The ICF was ratified by all 191 World Health Organization (WHO) member states at the World Health Assembly on May 22, 2001 as the universal standard taxonomy to classify and describe functioning, disability and health [2]. Thus, the ICF has become one of the most highly used frameworks in the world for conceptualizing functioning and disability and has been applied in a variety of contexts such as clinical care, public health, health policy development, education, as well as in clinical and disability studies research [3].

For the present study, we used the ICF to guide our development of new health informatics tools, including development of an ontology of mental functioning. The goal of the proposed functional-based ontology is to identify language used to describe the mental functioning of people experiencing functional difficulties as documented in clinical and disability program records. We operationally defined mental functioning as the *mind-directed observable external behaviours* that represent what people actually do (or do not do) in response to decisions occurring during real-time transactions as they unfold moment by moment in daily life and over time. Our conceptualization of mental functioning aligns with the ICF component of activities and participation.

Mental functioning is an important area of inquiry from the perspectives of public health (such as suicide prevention), health policy (such as disability program eligibility), and overall individual level health and well-being. However, the characterization of mental functioning brings the challenges of being less observable than

physical functioning and heavily influenced by factors within and outside of the person. While the ICF characterizes the language of mental functioning, it was not intended to, nor does it, depict the relationships between these elements. Furthermore, concepts within the ICF describing mental function (body function) versus mental activities overlap which is problematic for the purposes of classification and structuring ontologies of mental functioning. We delineate the problems we encountered using the ICF to characterize mental functioning and describe how we restructured and adapted the ICF to characterize mental functioning more fully, highlighting features of the ICF that were helpful and those where greater conceptual and organizational refinement would be beneficial.

Use case

In 2008, the Rehabilitation Medicine Department of the National Institutes of Health (NIH) Clinical Center entered into an agreement with the U.S. Social Security Administration (SSA) to develop novel analytical tools and assessments to improve its disability determination processes. This work is aimed at addressing the accuracy, timeliness, and consistency of SSA's existing processes which often require adjudicators to review volumes of medical records for information relevant to their disability determination processes. Improving the efficiency of this process could result in gains for the SSA as well as the millions of individuals that apply for disability benefits annually.

By intention, the work at the NIH involves a diverse interdisciplinary team of scientists, including those in health informatics, mathematics, statistics, computer science, public health, and healthcare. With the ICF as our framework, we suggested that focusing on the alignment between the activities that individuals are able to do in the context of the demands of jobs would better inform disability determination compared to information on health conditions and impairments. Thus, we focus on function at the activity level of the ICF for this work.

We have used natural language processing (NLP) methods on thousands of clinical records from the NIH Clinical Center as well as documents generated as part of the application process for SSA disability benefits to "teach" machines how to identify and extract information on functioning. Machine models and algorithms are developed that then translate into user-friendly tools that could potentially help SSA adjudicators search for and quickly find information of interest to aid decision-making in the disability determination process. We have used the ICF in past work as a framework for identifying and extracting information at the activity level of the ICF in the domains of mobility as well as self-care and domestic life [4–6].

Our current work is focused on identifying information on mental functioning at the ICF activity level, including interpersonal interactions and relationships, cognition, and communication. Characterizing the mental functioning of claimants whose primary disability stems from a mental impairment presents a considerable challenge when applying NLP methods due to the degree of inferential documentation, semantic ambiguity, context dependency, and limited observability of the actions. These challenges led to efforts to develop an Ontology of Mental Functioning (OMF) to permit better classification, coding, and distinction of related concepts.

Aims of the paper

- Provide a conceptualization of mental functioning that could structure the development of clinical informatic evidence-review tools for disability determination.

- Describe how we restructured and adapted the ICF to characterize mental functioning more fully, highlighting features of the ICF that were helpful and those where greater conceptual and organizational refinement would be beneficial.

Health informatics and ontologies

This section describes the relationship between health informatics and ontologies and how they serve as a foundation for natural language processing methods as applied to clinical information. Health informatics is an interdisciplinary field that develops innovate methods and technologies to organize and analyze health care data for the purposes of improving health care outcomes [7, 8]. Health informatics is the intersection of information, or library science and computer science, applied in the health care domain. The data at the core of this field is the clinical and medical documentation done by health care providers about their patients (via electronic patient record repositories). Extracting, organizing and analyzing health information provides knowledge that can be used to predict, correlate, and evaluate intervention outcomes. Such analyses can predict trends of diseases and drive decisions such as where to stock up on medications or which procedures work better than others, and can guide funding decisions such a need to better understand why patients with certain conditions are using emergency care in increasing numbers [9, 10]. Health informatics includes research that identifies pathologies. In addition, it catalogs whole-body functioning to document patient progress or decline and thereby informs decisions about the effectiveness of healthcare. This type of information also informs health policy since it is useful for the purposes of making determinations about disability benefits in the context of national disability programs. In summary, health informatics informs health research, health policy, and health care outcomes that benefit the health, quality of life and well-being of people and populations.

A subfield of health informatics, known as clinical Natural Language Processing (cNLP) involves the development of computer models and algorithms that train machines to read clinicians' notes, and identify and extract clinical text, or mentions, that represent concepts of interest. Domain ontologies help with interpreting and explaining a particular phenomenon, and in this way, guide cNLP by deeming what information is important to collect in clinical and medical documentation and where it can be found.

Domain ontologies organize concepts and serve the purpose to catalog the known entities within a particular domain of interest. A domain ontology includes a parts list, that is the list of concepts, a dictionary that defines each concept, and a list of explicit relationships between the concepts. A domain ontology pragmatically describes a field of endeavor. In practice, domain ontologies provide a bridging mechanism, an interlingua of knowledge communication between clinicians who use and document the concepts of a domain, and computer algorithms that find and make sense of the concept mentions found in their notes. Domain ontologies have terminologies attached to them that are a dictionary of terms that list and define each concept and assign explicit relationships between the concepts. Some examples of terminology platforms that are used in informatics research to capture and analyze health data are the Unified Medical Language System® (UMLS) [11], the Systematized Nomenclature of Medicine - Clinical Terms (SNOMED) [12], and The Diagnostic and Statistical Manual of Mental Disorders (DSM) [13]. These terminologies represent and reflect the language clinicians use in their documentation.

Ontologies about mental functioning are surfacing in health informatics, in large part to support reasoning and decision-making processes that can impact behavioral health care outcomes [14, 15]. However, the body of work related to mental functioning ontologies is sparse and has focused mainly on body-level mental functions [1] and behavioral health information technology [16]. Existing terminologies used in cNLP, such as SNOMED [12], MeSH [17], PsycInfo [18], and MEDCIN [19] are also very limited in conceptualizing mental functioning beyond biomedical or pathological spheres. Our work provides a complimentary perspective of mental functioning at the ICF level of activities and participation [1] as human behaviors related to mental functioning can be observed in daily life activities. The domain of mental functioning, from the perspective of an observer, as opposed to a personal or patient perspective, is less codified in existing medical terminologies, as mental functioning is often documented via transforming patient sourced mentions into clinician observations. We endeavor to better codify what we understand to be mental functioning through the creation and curation of a domain ontology as part of our pursuit to find mental functioning mentions in clinical text.

The ontology effort involves codifying what we understand to be the domain of mental functioning, and to express that codification within a *domain ontology*. As with other ontology development endeavors, our first steps involved researching and reusing what has already been done in the field, including what is useful from the ICF. Building an ontology is not our primary goal. We are developing it as a means to define, scope, express, and codify our current understandings in such a way that both domain experts/clinicians and informaticists can refer to and understand. As such, our initial efforts are focused on the knowledge acquisition and expressiveness aspects, rather than on developing an ontology that adheres to more formal ontology principles. Formal ontology principles include being able to automatically compute semantics, remaining consistent even as new content is added, be context independent, and accommodates different levels of granularity. Our methodology, or "*methontology*" is an adaption of methods that have been previously outlined [20–23].

A critical first step in developing a domain ontology is conceptualizing and defining key terms and constructs related to the particular phenomenon of inquiry. Next, we delineate how mental functioning was conceptualized for the purposes of building an Ontology of Mental Functioning, that is proposed and still under development.

Conceptualizing mental functioning

Human functioning involves both mental and physical components and is a complex interplay and transaction between the person and their roles, the activities in which they participate, the nature of these roles, and the environment in which activities occur. Our focus is specific to mental functions and functioning at the activities and participation level which involve cognitive and psychological processes. This requires distinction between activities that do, and do not, reflect mental functioning. Therefore, for the purposes of building an ontology of mental functioning, we differentiate all processing related primarily to physical functioning from that of mental functioning, and focus specifically on the cognitive, and psychological processes involved in daily life activities. Mental functioning is reflected as mind-directed behaviors that are within the individual's voluntary and conscious control, therefore we exclude any automatic or reflexive responses. We differentiate mind-directed voluntary behaviours from behaviours that are out of voluntary control, unconscious or subconscious, but recognize both types of behaviours are nonetheless inferred to be initiated, sustained and terminated by mental activity.

In the following section we will discuss which ICF classifications and their relationships were helpful in conceptualizing mental functioning, and where challenges utilizing the ICF occurred that warranted other resources to address gaps in conceptualizations, terminologies and definitions.

Scaffolding the ICF for an ontology of mental functioning

In the ICF, the activities and participation component delineates functioning from the perspective of the individual. Functioning at the activities and participation level is the outcome of a transactive process between contextual features (including personal and environmental factors), and the person's health condition, body structures and body functions [1]. Functioning involves both mental and physical processes and abilities. However, as mentioned earlier, for the purposes of building an ontology of mental functioning, our focus is primarily on the cognitive and psychological processes and abilities that drive the physical act of doing. In the next section we discuss how and why ICF concepts were adopted, modified, or reclassified for the purposes of developing an ontology of mental functioning (Figure 1).

Key components of the ontology of mental functioning

Mental functioning is observed as outward mind-driven non-reflexive behaviors that people do as they participate in activities within certain contexts and environments. We define mind-driven as behaviour initiated by mental activity. We have made an intentional decision to use "mind-driven" rather than volitional behavior because thoughts and feelings that are driven by the mind and influence activities are not under complete volitional control. For example, a person with a brain tumour or schizophrenia may experience delusions that lead to an impulse to step into traffic without concern for being hurt or lead to bizarre interpersonal behaviour. Mind-driven behaviours that reflect mental functioning are the outcome of a transactive relationship between the person, the activities the person participates
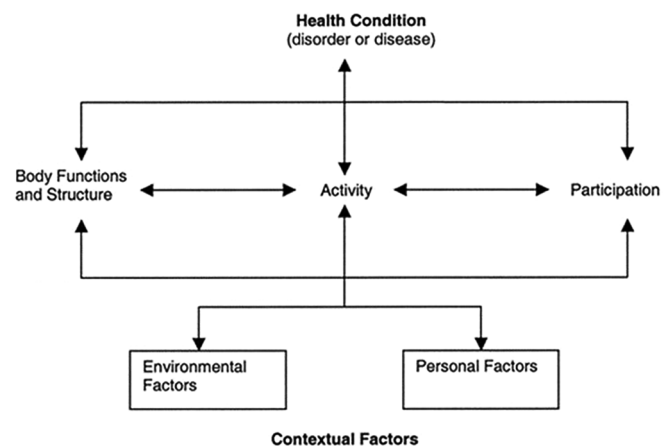

Figure 1. The ICF Scheme: Interactions between components (WHO, 2001). ICF schematic showing activity as the central concept that both influences and is affected by one's health condition, body functions and structures, contextual environmental and personal factors and participation.

in that are within specific external contextual situations and environments [24] and can be conceptualized in Figure 2 below. The key components of the person, activities and participation, and external factors are the basis for our Ontology of Mental Functioning and are described in detail in the next section.

The external world – context and environment

ICF contextual factor: environment

The terms context and environment are often used interchangeably in the literature [25–27] and there is great variability in the way they are defined [28]. Contextual factors are defined broadly in the ICF as "the complete background of an individual's life or living" and include two components: environmental factors and personal factors. Environmental factors are external to the individual and are divided into two levels –individual and societal. The individual environmental level is made up of physical and material features, and settings, that are more immediate, proximal, and tangible for the person; and also, social features such as others who come into direct contact with the person. The societal environmental level is more distal to the individual but has impact on a person's life and living and includes formal and informal social structures and networks, ideologies and attitudes, policies and laws; communication and transportation services; community and social services; and health care systems among others [1].

Ontology: external factors

In our proposed OMF, both contextual factors and environmental factors are considered to be external factors that exist outside of the individual and are the surrounding life world of the person. Like the ICF, the OMF recognizes the potential of external factors to support or hinder the individual's performance and participation in activities. Contextual and environmental factors may impose demands and exert influence directly or indirectly upon the person. Unlike the ICF, however, we make a distinction between factors that are contextual and factors that are environmental.

Contextual factors in the ontology of mental functioning

In the OMF, context is defined as intangible features that include factors such as a person's life circumstance within a particular situation that can influence participation. These include cultural factors such, social norms, practices and ideologies; temporal factors such as historical situation and natural weather seasons; sociopolitical factors such as societal attitudes, government policies, laws, health and social systems; and situational factors that include the current life event of the person [26, 29, 30]. Context is conceptualized more expansively in the OMF than in the ICF. A broader sense of context expands perspectives for understanding mental functioning as mind-driven behaviours in relation to a particular place, at a particular time, in a particular situation. Behaviour is highly context-dependent and context is also an important consideration in how one's behaviour is determined by others to be appropriate or reasonable. We conceptualize context to be a broader construct with a greater scope than environments; and that environment is encompassed within context (see Figure 3 below).

We consider the ICF's societal environmental factors to equate with our concept of what is contextual. Context in the OMF includes external events and situations that are beyond individual environmental physical and social factors. Examples of a more expansive view of context are a person's life world situations of time and place such as living during the time of the Covid pandemic, living in a time of war or peace, or living in a digital and virtual age.

A more expansive view of context provides a greater understanding of mental functioning as observable behaviors that indicate how the contextual situation is considered when making decisions about how to respond within a given situation. For
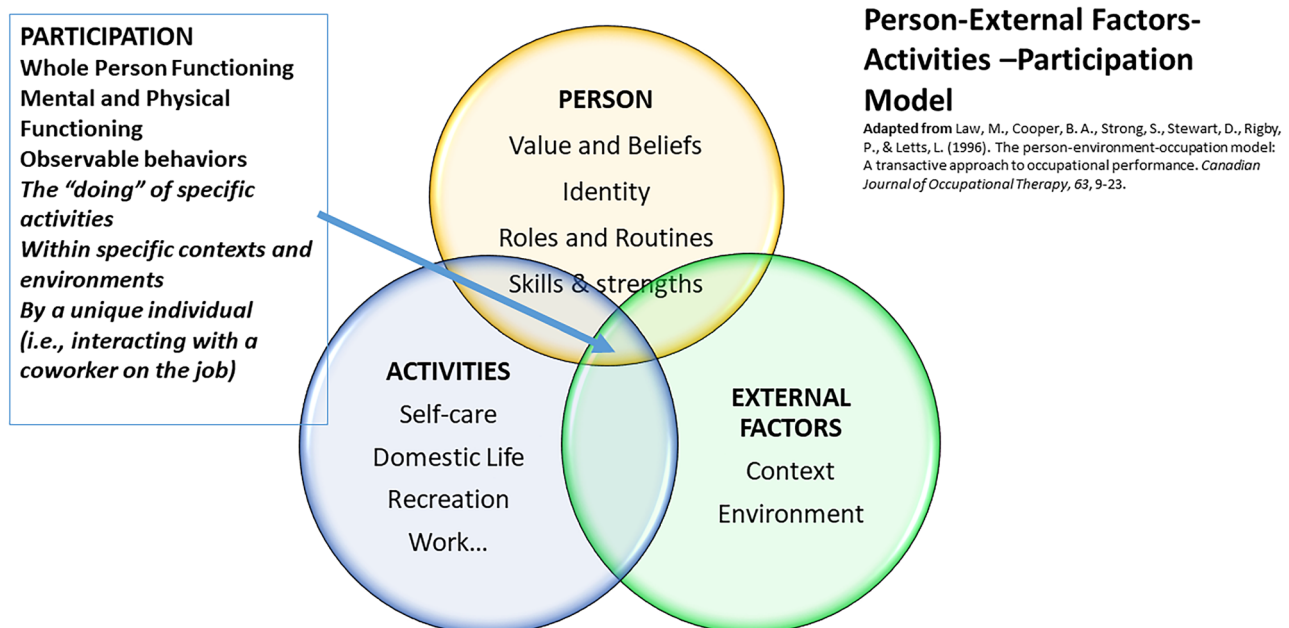

PARTICIPATION
Whole Person Functioning
Mental and Physical Functioning
Observable behaviors
The "doing" of specific activities
Within specific contexts and environments
By a unique individual (i.e., interacting with a coworker on the job)

PERSON
Value and Beliefs
Identity
Roles and Routines
Skills & strengths

ACTIVITIES
Self-care
Domestic Life
Recreation
Work...

EXTERNAL FACTORS
Context
Environment

Person-External Factors-Activities –Participation Model
Adapted from Law, M., Cooper, B. A., Strong, S., Stewart, D., Rigby, P., & Letts, L. (1996). The person-environment-occupation model: A transactive approach to occupational performance. *Canadian Journal of Occupational Therapy, 63*, 9-23.

Figure 2. Person-external factors-activities-participation model.
A 3-circle Venn diagram showing participation as the intersection of the three major concepts: the person, the activities, and external factors of environment and context.
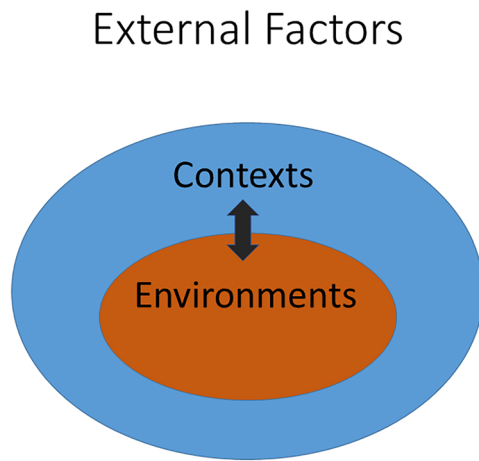
External Factors

Figure 3. Relationship of environments and contexts as external factors. External factors shown as context and environments, with environments represented as an inner most circle contained and relational within the larger circle representing context.

example, waiting 45 minutes in a restaurant before the only waiter working is able to take one's order is normally unacceptable to patrons. However, how one would decide to respond in this situation may change when considering the context of the Covid pandemic and understanding what the situation may be for the one waiter who did show up for work. These interactions are taking place in the individual's immediate physical and social environment. Interactions are affected by societal environments, such as government regulating public health behaviors. It is however the larger situation, the contextual situation of the Covid pandemic in this example, that is important to understand and consider in relationship to adaptive mental functioning. These examples represent contextual factors that are more distal to the individual. Distal contextual features influence the person and their behaviors, but they are less tangible, more abstract, and less malleable for the person to change and influence.

The situational background of one's life also provides proximal contextual information such as the context of a job interview, the context of a meeting with work colleagues, dinner out with friends, etc. Understanding the more immediate context is also important for adaptive mental functioning. Contextual factors that are more proximal to the individual may be perceived as more relevant in day-to-day life, and less abstract. The person has greater agency to change and influence their proximal contextual situation, such as leaving an unsatisfying job for one that is more rewarding (changing the job context) or limiting the number of friends one goes out to dinner with for a more quiet and intimate evening (changing the social activities context). Proximal contexts provide more possibilities and opportunities for the individual to exert an influence as they are more tangible and malleable than contexts that are more distal or far-removed from the individual.

Of note – the relationship between proximal contexts and proximal environments is interwoven, but distinguishable. Proximal environments are more tangible and malleable by the individual. Changes one makes in their physical and social environments directly impacts one's immediate contextual situation. And vice versa – changes to one's contextual situations usually involves changes a person makes to their immediate physical and social environments. It is the individual's manipulation of their proximal environments that can influence the person's contextual situation. For example, in the context, or situation, of "looking for a job", efforts one makes within this context involve direct interactions with the physical environment, i.e., using a

computer to search for jobs online, and interactions with social environments, i.e., conversing with friends to network for jobs, or speaking with recruiters to obtain greater job details.

Contextual factors are also the situational background to one's life and living [1] and therefore can define one's roles and what constitutes appropriate behaviors based on socio-cultural norms within a given situation. For example, in the context of war, killing another human being is considered appropriate to the role of soldier. However, killing another human being in the context of civilian life is considered unlawful and punishable. Contextual factors are less mailable for the individual person to change and influence.

In summary, proximal and distal contextual factors are an important consideration for understanding human behaviors indicative of mental functioning. The more proximal the context is to the individual, the more agency the person has to change and influence the context they are in. Distal contexts, though less mailable and less able to be influenced by the individual, also impact the person's life and living and the volitional choices people make about how to act.

Environmental factors in the ontology of mental functioning

In our proposed OMF, environmental factors are defined as tangible features within the immediate space one occupies. These features surround the person proximally and include: (1) physical environments (natural world; human-made objects, technology, and built structures), and (2) social environments made up of other people or animals that provide practical physical or emotional support and includes the attitudes of others toward the person (open, friendly, prejudice, etc.) [1, 31].

The individual environmental level, as defined by the ICF, aligns with our conceptualization of what are considered to be environmental factors in the OMF. In the ICF, the setting one is in, such as home or school, is recognized as the immediate physical environment made up of material features one interacts with. Likewise, the social environment is understood as other people in one's surrounding space with whom there is direct contact. Environmental factors are dynamic and impact and exert influence directly upon the person and their behavior occurring moment by moment, and over time. They are more malleable for the person to influence and shape due to the direct transactional relationship that exists between the person and their physical and social environments.

The internal world – the person

People experience the world and interact with the world through their body. The internal world can be understood as the person beginning from the skin and inward, made up of intra-individual factors [32]. Body structures are part of that internal world of the individual therefore are not seen as separate from the person. For example, the body structure of the brain is inside the skull and mental functions that process information about the external world occurs in the brain. We conceptualize body structures and body functions as part of the internal world of the person. For example, the integrity of the structure of the lens of the eye is reflected by the presence or absence of the health condition of cataracts. This in turn affects the function of the eye, preventing a sharply defined visual image from reaching the retina, resulting in blurred vision. In everyday life, blurred vision can result in falls due to poor perception of objects in one's environment. Thus,

body functions (i.e., visual perception) are, to some extent, dependent on the integrity of body structures (i.e., the eye). Body structures and functions, and health conditions, are unique and part of the individual and the integrity of these functions can impact one's functioning in daily life activities.

Mental functioning is expressed as outward mind-driven behaviors that are the result of conscious decisions a person makes about how to act within a given situation based upon their environmental interactions, and the nature of the activities engaged in. The person, therefore, is a critical factor in understanding mental functioning. However, we concur with others, that it is difficult to determine where the person is actually reflected in the ICF scheme [33].

In the ICF scheme, body functions and structures, and a person's health condition(s), are represented as separate entities from personal factors. For understanding mental functioning at the level of the whole person, it was difficult to conceptualize anatomical concepts of one's health condition, body structures and body functions as separate from the person, since they are an intrinsic part of the person. In our conceptualization of mental functioning, we position health condition(s), and body structures and functions as factors that are part of the person (intra-individual), and not separate from the person (extra-individual). The ICF's positioning of personal factors as context, and body structures and functions and health conditions as separate unique components, fragmented one of our central concepts in the OMF which did not serve our conceptualization of the person as a whole complete being. Nesting the ICF components of personal factors, health conditions, body structures and functions as parts that make up the Ontology category of "person" provided a more coherent perspective and understanding of the person as a whole. Distinguishing personal factors as internal and intrinsic to the person, from external factors outside of the person, allows for a clearer distinction between concepts and their relationships, and thereby can provide greater conceptual clarity of mental functioning.

In the ICF [1], a person's unique background, life, and living that are not part of a health condition or health state is recognized as a contributory factor to understand a person's functioning and disability and considered a personal factor. However, personal factors have not been classified in the ICF and have been placed as a contextual factor in the ICF scheme. In the OMF, personal factors are not considered contextual, but are seen as an integral part of the person. The background of an individual's life, and who that person is as an individual, is a critical and important piece of the puzzle in understanding a person's mental functioning.

The ICF provides a brief description of what personal factors may include, and some descriptions were helpful and included in the personal background factors of the Ontology. Some descriptors of personal factors in the ICF, however, were confusing and seemingly contradictory, such as excluding a "health condition or health state" [1, p.17], while including "other health conditions" [1, p.17]. In our Ontology, other health conditions and comorbidities are classified as part of one's health condition, and not as a contextual personal factor as done in the ICF. We also consider "past life events and concurrent events" [1, p.17] to not be a personal factor as described in the ICF, but a contextual factor since it is referring to a situational event of a temporal nature.

Personal background factors were added in the OMF as part of the person, and relevant descriptors of personal factors from the ICF were included here. We subclassified personal background factors into three main sub-components: (1) demographic factors, (2) biographical factors, and (3) psychological factors. Demographic person factors may include aspects such as age, gender, race,

living situation, developmental stage, etc. Biographical factors represent one's life history, personal context, life experiences, relationships and roles, personal culture, education, profession, etc. Psychological factors involve such things as one's locus of control, personal causation, interests, volition, behavioral patterns and habits, will and intent [34]; and one's spirituality and beliefs including values, ethics and moral compass. The Ontology also recognizes mind as a non-anatomical mental functioning concept internal to the individual.

In summary, the person is seen as a key component in our proposed OMF and factors that make up the person include (1) body structures, (2) body functions, (3) health conditions, and (4) personal background factors.

Activities and participation

The activities and participation component of the ICF aligns with the Ontology conceptualization of mental functioning as outward observable behaviors of what people do. In the ICF, activities are defined as "the execution of a task or action by an individual" [1, p.10]. Similar to the ICF, we define activities as the doing or performance of tasks or actions that are part of the steps or process for participation in a life situation. For example, participating in the life situation of a day at work may involve many activities such as using a computer, taking breaks as needed, organizing tasks to meet deadlines and attending virtual team meetings. Participating in the role of parent involves many types of activities one needs or is expected to do to care for a child. Participation is defined in the ICF as "a person's involvement in a life situation" [1, p.10]. We have expanded upon the ICF definition and operationalized participation to mean engagement in a life situation that is made up of activities that one wants, needs and/or is expected to do within their roles, environment, and cultural context [35].

The merging of activities and participation as one component in the ICF taxonomy, when these are two distinct constructs, is well known to have created conceptual ambiguity [36]. The activity and participation component in the ICF includes domains that "denote aspects of functioning from both an individual or societal perspective" [1, p.8]. In the ICF, activities "represent the *individual* perspective of functioning" and participation "represents the *societal* perspective of functioning" [1, p.213]. Participation is defined as "involvement in a life situation" with a performance qualifier including the "lived experience" of the person in context [1, p.213]. Is participation then the internal lived experience of the individual, or an external perspective of how others view one's involvement in life situations? We find these definitions somewhat confusing as the ICF adopts the perspective of the person, yet a societal perspective of participation is by definition a perspective outside of and separate from the person. Though we recognize that whose perspective is adopted is an important consideration to understand activities and participation, the distinctions about perspectives and how they are determined in the ICF is not clear.

We consider an individual's perspective to be a part of the person and highly influenced by personal factors such as life experiences, values and beliefs. The OMF can be used conceptually to understand and explain behaviours indicative of mental functioning from either the individual's perspective or the perspective of others within the person's environment. For the purposes of our use case to determine work disability, the perspective of others in the external environment is adopted for decisions to be made about a claimant's cognitive and psychosocial ability to

participate in the activity of work and adapt to work activity demands.

For the most part, the range of activities people participate in have been well classified and defined in the ICF, and these classifications have been adopted in the Ontology. We also note that consciousness is necessary for participation to occur. For example, though sleep activity itself is an observable behavior, a person cannot be said to be participating in sleep since consciousness and volitional activity are suspended. However, the person can be said to be participating in self-care behaviors that includes the activity of sleep. The mental functioning component in sleep is in the conscious activities involved for sleep preparation, such as setting up the environment to be dark, quiet and cooler, to enable sleep, and ensuring sleep continues after being interrupted by night-time toileting and hydration needs for self-care [35].

Feedback

Feedback is the instantaneous sensory information provided to the person as they participate in activities and interact within their world during daily life activities. As people participate in activities and interact within their world, they are continually receiving sensory information about their world, including outcomes of their actions during participation in daily activities. As feedback, sensory information is continually processed and appraised, allowing the person to adjust their behaviors and actions and adapt to the unfolding situation at hand. Adaptive responses produce favorable outcomes for the person, maladaptive responses produce poor or less-favorable outcomes. This information is then inputted back into the system as sensory information, allowing the person to adjust to the changing situation of life as wanted or needed.

Sensory information arises from two sources: one's internal body and one's external environment. External feedback is sensory information received from the outside physical and social environments and contextual situation about the results of one's actions. Internal feedback is sensory information to the brain about what is going on internally within one's body such as how one is feeling physically and emotionally, and how one's body is reacting to the results of one's actions (i.e., feeling pain relief after taking pain medication, feeling sad after hearing distressing news, or feeling joint pain after overdoing exercises).

The brain receives sensory information via sensory afferent neurons (auditory, visual, gustatory, olfactory, tactile sensors), that provide information about sound, light, taste, odors, feel; and by the body's internal environment that senses body position in space, balance and movement through vestibular and proprioceptive sensors, and afferent neurons from internal organs and organ systems (i.e., cardiopulmonary system, digestive system, etc.). Sensory information provides moment by moment continual sensory feedback to the person about the results of one's actions within one's current context and environmental situation. For example, seeing friends laugh at a joke one just told gives visual and auditory sensory information that that joke told was perceived funny by others as was intended, or smelling something burning on the stove gives olfactory sensory information that perhaps the person forgot they had something cooking on the stove.

The ICF has no concept for feedback. However, this is an important conceptualization for mental functioning. We define feedback as instantaneous and continual sensory information received through the body about the results of one's actions within one's current environment and contextual situation. Based upon the actions, or lack of actions performed, a person is provided with real-time feedback about the results of their actions. Sensory information is continually received and processed in the brain, in a feedback loop, allowing the person to adjust their behaviors and actions through mental activity. Feedback appraisal is the central processing in the brain of the sensory feedback information received. This feedback loop of receiving internal and external sensory information, and processing and appraising this information, allows the person to make behavioral adjustments in order to adapt to a dynamic and constantly changing life world situations and experiences. Feedback highlights the transactive nature of person-environment interaction during activity participation.

Table 1 summarizes the reorganization of ICF concepts as applied to the proposed OMF. We have described areas where the ICF classification, conceptual definitions and the ICF scheme helped or hindered our work toward this end. In instances where the ICF hindered our work, we have explained why and describe how we rectified ICF concepts of functioning to align with our conceptualization of mental functioning for the purposes of developing an Ontology of Mental Functioning.

Discussion

All individual ICF components, concepts, classifications and their definitions had value and contributed to development of key categories in the proposed OMF. However, using the ICF alone to develop a comprehensive ontology of mental functioning posed some challenges. Key conceptual challenges related to the way in which personal, environmental, and contextual factors were classified and conceptualized in the ICF.

The person is a central concept in the Ontology. However, it is difficult to conceptualize where the person actually is in the ICF scheme, and to understand personal factors as separate from the individual. In the OMF, anything internal or intrinsic to the individual is considered an individual attribute and therefore part of the person. If personal factors are part of a person, then it is incongruent to place personal factors as a contextual factor, conceptually "outside" of the person. Additionally, the ICF has no formal classification of personal factors, though some brief descriptors of personal factors are provided. In the OMF, the person is understood as having unique, idiosyncratic and individualistic *personal background factors* that include: *demographic factors* (i.e., age, gender, social status); *biographical factors* (i.e., roles, life experiences); and *psychological factors* (i.e., personality, interests, volition). We reclassify ICF components internal to one's body as a part of the person; therefore, the OMF catalogues ICF *body structures, body functions and health conditions* as person factors.

Contextual factors in the ICF were particularly incongruent conceptually for the Ontology since the ICF considers both intrinsic personal factors and extrinsic environmental factors to be contextual. In the resultant OMF, contextual factors are considered to be external and outside the individual, and personal factors to be internal and part of the person. Contextual and environmental factors are sub-classified in the OMF as a part of external factors – that is anything outside the person in the person's external life world.

Context is a contested concept in the literature and has not been well defined. It is often used interchangeably with environment; however, we have shown how distinctions can be made between what is environmental and what is contextual. As such, we parsed the ICF's classification of environment to align with the way it is conceptualized in the Ontology. The ICF's *societal*

Table 1. Reorganization of ICF concepts as applied to the ontology of mental functioning.

ICF Scheme & Concepts	Helped our work	Hindered our work	Rectified in Ontology of Mental Functioning
Contextual Factor – Environmental Factors	Definitions of environments include the immediate physical environments and social environments where direct contact with others takes place (at the ICF Individual level). "External factors represent the circumstances in which the individual lives" (p. 17).	Inconsistent use and overlap in definitions of terms such as external factors, contextual factors, individual environmental factors, and societal environmental factors. ICF contextual factors are made up of both internal (personal) and external (environmental) factors, making it difficult to determine their relationship and influence upon each other. Conceptual ambiguity regarding contexts and environments.	Anything outside of the person is the external world and is made up of **external factors**. *External Factors* are made up of two distinct components: Context and Environments *Context:* The situational background to one's life and living; the person's distal and proximal life world situations of time, place, and purpose. Context equates with the ICF *Societal* environmental level made up of environments that are more distal in relation to the person (cultural, sociopolitical, economic, etc.) *Environment:* Environment equates with the ICF *Individual* environmental level made up of physical and social features more proximal and malleable by the individual.
Contextual Factor - Personal Factors	Recognized as an important component in understanding functioning and disability. The ICF provides some brief descriptors of Personal Factors.	Not sure where the person is in the ICF scheme. As personal factors are considered part of a person, it is difficult to conceptualize personal factors as separate from the individual. If personal factors are part of a person, then it is incongruent to place personal factors as a contextual factor, conceptually "outside" of the person. No classification of Personal Factors.	The person is a central concept in the Ontology. Anything **internal** to the individual is considered part of the person. The person is understood as having unique, idiosyncratic, and individual: *Personal Background Factors:* ・ Demographic factors ・ Biographical factors ・ Roles ・ Life situation ・ Psychological factors We reclassify ICF components internal to one's body as a part of the person; these include: *Body Structures* *Body Functions* *Health Conditions*
Health Condition	Recognized as an important concept to understand functioning.	Health conditions are a separate conceptual entity outside the person.	Health condition is considered a person factor as it is something internal to the individual. The person is *someone with* a health condition, including co-morbidities.
Body Structures	Body Structures are well defined and classified.	Body structures are a separate component from personal factors.	Body structures are internal and unique to the individual.Body structures are reclassified as part of the person, rather than a separate component. Perceiving and processing information from the external world is dependent upon the integrity of one's body structures.
Body Functions	Body functions are for the most part well defined and categorized.	Missing important non-anatomical body mental functions salient to mental functioning such as volition, intent, will, and mind.	Body functions are internal and unique to the individual. Body functions are reclassified as part of the person, rather than as a separate component. We include non-anatomical mental functions that account for variations in the reasons persons choose to act or not act (or participate or not participate).
Activities	Defined as "the execution of a task or action". Some activity domains such as mobility, self-care, domestic life, major life areas and community, social and civic life provide descriptions of actions one would do duringparticipation. Activity limitations are "difficulties an individual may have (internally) in executing activities".	Some activity domains including learning and applying knowledge; general tasks and demands and parts of communication are more about a quality of participation in an activity and include more about cognitive internal skills rather than the actual DOING. This gets messy as it overlaps with body (mental) functions. Memory is a salient mental function that is not clearly represented in the Activities and Participation component. Activities represent the individual perspective of functioning.	We take activities and participation, in the sense of "Participation through Activities" to mean one's observable behaviors. An individual's perspective is considered to be a part of the person and involves the perspective from one's internal world. Activities are operationalized in the Ontology as the doing or performance of tasks or actions that are part of the steps or process for participation in a life situation. For example, the activity of showering denotes participation in self-care.
Participation	Defined as "involvement in a life situation". Participation restrictions are "problems an individual may experience in involvement in a life situation".	Broad definition. How one experiences something is very subjective and an internal personal phenomenon. The ICF's societal perspective on participation diverges from the person's lived experience of participation.	Lived *experience of involvement* is considered a personal factor.Participation is operationalized as engagement in a life situation that is made up of activities one wants to do, needs to do, or is expected to do within one's roles, environment, and cultural context.
Feedback	No conceptualization of feedback in the ICF.	No conceptualization of the adaptation process that allows the person to receive and respond to sensory information as the person interacts moment by moment with their environment.	We introduce the concept of feedback and feedback appraisal. Feedback provides sensory input to the person about the external world and the internal world of the body. Feedback appraisal is the neurocognitive processing of feedback information, allowing the person to adjust their behaviors and actions as they interact with and adapt to their environments and contextual situations.

environmental level was reclassified as a contextual feature, as cultural, sociopolitical and economic features refer to the external world that is more distal, more abstract, and less malleable for the individual, but does frame and impact how the person lives, functions, and conducts their life. The ICF's *individual* environmental level was squarely aligned with the concept of environment in the Ontology, recognized to have physical and social aspects that are more immediate and proximal to the individual, enabling more direct interactions with others, and using tangible objects in activities.

With key components in the ICF classified as separate entities, it was difficult to conceptualize the person as a whole - a critical major component to understand mental functioning in the OMF. For our purposes, the schematic relationship shown between key components did not fully represent the complex nature of mental functioning that results from a transactive, rather than a linear interactive, relationship between a person, their environment and context, and the activities the person participates in.

The ICF also had no concept for feedback or feedback appraisal, important conceptualizations for mental functioning that considers the person's ability to adapt behaviors to unfolding situations through transactions within their world in context and judge the outcomes of one's actions. In summary, all ICF components in and of themselves were useful for the OMF, but most required reorganization and re-classification to align conceptually with the Ontology.

In the context of the SSA use case, it is essential to highlight that disability is not an individual attribute, but is a resultant outcome of the transaction between the person and their environment. Function is dependent on a particular environment and situation at a particular time [31]. For example, a person functioning in their own home that is well adapted may have no experience of disability, but that same person may experience disability in a work setting that lacks environmental supports the person requires. The authors point out implications for disability determination as it relates to gainful employment, that should be tied to a very specific time, place, set of skills and job type. Heerkens and colleagues [37] have suggested the ICF scheme needs to bestow more importance on the environment by having it surround all other components to stress the importance of these factors in functioning.

Implications for policy

The SSA is responsible for processing disability applications and determining eligibility for benefits. SSA's policy criteria for determining mental functioning ability for a claimant with a mental impairment are: (1) understand, remember, and apply information, (2) interact with others, (3) concentrate, persist, and maintain pace, and (4) adapt or manage oneself [38]. Determination of presence and severity of disability is an arduous task for SSA adjudicators who need to search through a claimant's medical records for evidence of functioning bench-marked against this policy criterion.

Natural language processing can be of benefit by providing tools that can automatically extract mental functioning information from claimant's medical records. NLP methods use machine learning models that are based and trained on the clinical annotations done by human experts. In computer science, ontologies determine what information is important to capture to guide the building of models for machine learning. Our aims for developing and proposing an Ontology of Mental Functioning is to support NLP efforts to build tools designed to extract this mental functioning information from clinical records. These tools can assist SSA's disability determination adjudicators to quickly find mental functioning information in claimant's medical records and improve the consistency of locating this information which may lead to improvements in the overall disability determination process.

Conclusions

We have shown the usefulness and challenges applying the ICF as a framework to conceptualize and categorize mental functioning to develop an ontology that can identify this type of information at the activity level for natural language processing. The proposed OMF can be used to guide development of NLP tools that could potentially support the disability determination process of the U.S. Social Security Administration for claimants with a mental disorder.

Challenges using the ICF to conceptualize mental functioning stemmed from a fragmented picture of whole person functioning due to a lack of clarity of where the person was located in the ICF, a lack of formal concepts and classifications of personal factors, ambiguity of contextual and environmental factors and how concepts intrinsic or extrinsic to the individual were classified, and a lack of conceptual clarity as to the relationship between some key components. In addition, the notion of the feedback loop conceptualization of the individual's ability to adapt and change behaviours based upon person-activities-environmental transactions is lacking. Even so, all ICF key components, concepts, classifications, and their definitions had value and were rearranged, reclassified and incorporated into the OMF. Though we recognize the ICF was not designed as an ontology, field testing the ICF for language that represents mental functioning at an activities level has shown areas where the ICF can be further developed to benefit health informatics research targeting functioning information from health records, and aid the disability determination adjudication process for social security.

Acknowledgements

Disclosure statement

Funding

References

[1] World Health Organization. International classification of functioning, disability and health: ICF. Geneva: world Health Organization; 2001.

[2] World Health Organization. World Health Assembly endorses WHO's strategic priorities 2001a. Available from: https://www.who.int/news/item/22-05-2001-world-health-assembly-endorses-who-s-strategic-priorities.

[3] Cerniauskaite M, Quintas R, Boldt C, et al. Systematic literature review on ICF from 2001 to 2009: its use, implementation and operationalisation. Disabil Rehabil. 2011;33(4):281–309. doi: 10.3109/09638288.2010.529235.

[4] Thieu T, Maldonado JC, Ho PS, et al. A comprehensive study of mobility functioning information in clinical notes: entity hierarchy, corpus annotation, and sequence labeling. Int J Med Inform. 2021; Mar147:104351. doi: 10.1016/j.ijmedinf.2020.104351.

[5] Newman-Griffis D, Maldonado JC, Ho P-S, et al. Linking free text documentation of functioning and disability to the ICF with natural language processing. Frontiers in Rehabilitation Sciences. 2021.

[6] Zirikly A, Desmet B, Porcino J, et al. editors. A whole-person function dictionary for the mobility, self-care and domestic life domains: a seedset expansion approach. Proceedings of the Thirteenth Language Resources and Evaluation Conference, Marseille, 2022 June 20-25. LREC; 2022.

[7] Aickelin U, Chapman WW, Hart GK. Health informatics - ambitions and purpose. Front Digit Health. 2019;1:2. doi: 10.3389/fdgth.2019.00002.

[8] Ranallo PA, Kilbourne AM, Whatley AS, et al. Behavioral health information technology: from chaos to clarity. Health Aff (Millwood). 2016;35(6):1106–1113. doi: 10.1377/hlthaff.2016.0013.

[9] Levy CR, Zargoush M, Williams AE, et al. Sequence of functional loss and recovery in nursing homes. Gerontologist. 2016; Feb56(1):52–61. doi: 10.1093/geront/gnv099.

[10] Wojtusiak J, Asadzadehzanjani N, Levy C, et al. Computational barthel index: an automated tool for assessing and predicting activities of daily living among nursing home patients. BMC Med Inform Decis Mak. 2021; Jan 0921(1):17. doi: 10.1186/s12911-020-01368-8.

[11] Bodenreider O. The unified medical language system (UMLS): integrating biomedical terminology. Nucleic Acids Res. 2004;32(Database issue):D267–D270. (database issue):doi: 10.1093/nar/gkh061.

[12] SNOMED CT. [Internet]. Bethesda, MD: 2019 [cited 2022]. Available from: https://www.nlm.nih.gov/healthit/snomedct/index.html.

[13] American Psychiatric Association. Diagnostic and statistical manual of mental disorders. (5th ed.). Washington D.C.; 2013.

[14] Hadzic M, Chen M, Dillon TS. Towards the mental health ontology. IEEE International Conference on Bioinformatics and Biomedicine, Proceedings. 2008:284–288.

[15] National Academies of Sciences E, and Medicine. Ontologies in the behavioral sciences: accelerating research and the spread of knowledge. Washington, DC: The National Academies Press; 2022. English. (Kaplan RM, Beatty AS, editors.).

[16] Nagi SZ. Some conceptual issues in disability and rehabilitation. In: sussman MB, editor. Sociology and rehabilitation. Washington DC: American Sociological Association; 1965. p. 100–113.

[17] Medical Subject Headings (MeSH). [Internet]. Bethesda, MD: 2022. Available from: https://www.nlm.nih.gov/bsd/disted/meshtutorial/themeshdatabase/index.html.

[18] PsycInfo. [Internet]. Washington DC.: 2022 [cited 2022]. Available from: https://www.apa.org/pubs/databases/psycinfo/.

[19] MEDCIN. [Internet]. 2022. Available from: https://medicomp.com/medcin/.

[20] Chuprina S, Alexandrov V, Alexandrov N. Using ontology engineering methods to improve computer science and data science skills. Procedia Comput Sci. 2016;80:1780–1790. doi: 10.1016/j.procs.2016.05.447.

[21] Cozzi S, Martinuzzi A, Della Mea V. Ontological modeling of the international classification of functioning, disabilities and health (ICF): activities&participation and environmental factors components. BMC Med Inform Decis Mak. 2021; Dec 2921(1):367. doi: 10.1186/s12911-021-01729-x.

[22] Fernández M, Gómez-Pérez A, Juristo N. Methontology: from ontological art towards ontological engineering. AAAI-97 spring symposium series. Stanford, USA 1997.

[23] Noy NF, McGuinness DL, editors. Ontology development 101: a guide to creating your first ontology. Knowledge Systems Laboratory, Stanford University; 2001.

[24] Dunn W, Brown C, McGuigan A. The ecology of human Performance - A framework for considering the effect of context [article. Am J Occup Ther. 1994; Jul48(7):595–607. doi: 10.5014/ajot.48.7.595.

[25] Letts L, Rigby P, Stewart D, editors. Using environments to enable occupational performance. Thorofare, NJ: SLACK, Inc.; 2003.

[26] Clitheroe HC, Stokols D, Zmuidzinas M. Conceptualizing the context of environment and behavior. J Environ Psychol. 1998; Mar18(1):103–112. doi: 10.1006/jevp.1998.0091.

[27] Zhang BY, Kang J. Effect of environmental contexts pertaining to different sound sources on the mood states. Build Environ. 2022; Jan207(108456):108456. doi: 10.1016/j.buildenv.2021.108456.

[28] Moos RH. The human context: environmental determinants of behavior. New York: john Wiley and Sons, Inc.; 1976.

[29] Institute of Medicine. Disability and the environment. In: brandt EN, Pope AM, editors. Enabling america: assessing the role of rehabilitation science and engineering. Washington D.C.: the National Academies Press; 1997b. p. 147–169.

[30] Institute of Medicine. Models of disability and rehabilitation. In: brandt EN, Pope AM, editors. Enabling america: Assessing the role of rehabilitation science and engineering. Washington D.C.: the National Academies Press; 1997a. p. 62–80.

[31] Verbrugge LM, Jette AM. The disablement process. Soc Sci Med. 1994; Jan38(1):1–14. doi: 10.1016/0277-9536(94)90294-1.

[32] Felson Duchan J. Where is the person in the ICF? Adv Speech Language Pathol. 2004;6(1):63–65. doi: 10.1080/14417040410001669444.

[33] Kielhofner G. Model of human occupation: Theory and application. Baltimore, Maryland: lippincott Williams & Wilkens; 1995. (3rd, editor.).

[34] AOTA. Occupational therapy practice framework: domain and process. (4th ed.). Bethesda (MD): American Journal of Occupational Therapy. 2020;74:7412410010p1–7412410010p87.

[35] Hammel J, Magasi S, Heinemann A, et al. What does participation mean? An insider perspective from people with disabilities. Disabil Rehabil. 2008;30(19):1445–1460. 2008/01/01doi: 10.1080/09638280701625534.

[36] Heerkens YF, De Brouwer CPM, Engels JA, et al. Elaboration of the contextual factors of the ICF for occupational health care [article. Work. 2017;57(2):187–204. doi: 10.3233/WOR-172546.

[37] Heerkens YF, de Weerd M, Huber M, et al. Reconsideration of the scheme of the international classification of functioning, disability and health: incentives from The Netherlands for a global debate. [Article]Disabil Rehabil. 2018;40(5):603–611. doi: 10.1080/09638288.2016.1277404.

[38] Disability evaluation under social security. 12.00 Mental disorders - Adult [Internet]. United States government. 2023 [cited 2/24/2023]. Available from: https://www.ssa.gov/disability/professionals/bluebook/12.00-MentalDisorders-Adult.htm.