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The Concept of Exposure in Environmental Health for Nursing

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Abstract

Aim—To report an analysis of the concept of exposure in environmental health for nursing.

Background—The importance of the environment has long been recognized in nursing, although the nature and scope of the concept and how it influences health has varied over time. Exposure is the sufficient and necessary link between environment and health. In nursing practice, the word 'exposure' has been used frequently with no clear standard definition.

Design—Concept analysis using Kim's first level analytics.

Data sources—Chronological review (1980–2015) of the nursing science literature was conducted through ProQuest Dissertations and Theses and CINAHL, followed by a multi-disciplinary search through PubMed (1980–2015), texts and the Internet to compare definitions and measurements of exposure and related concepts.

Methods—Explicit and implicit conceptual definitions and measurements of exposure were identified, categorized and analyzed.

Results—The newly defined concept of *exposure* is a process involves three phases: 1. contact is made between a target and one or more agents in the same environment; 2. the agent accesses the target by one or more routes of entry; and 3. the agent enters the target by crossing a barrier or boundary. Existing measurements related to each phase are identified and discussed. Definitions of *target* and *agent* were refined for congruency.

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1. substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data;
2. drafting the article or revising it critically for important intellectual content.

* http://www.icmje.org/recommendations/

Conclusion—Consistent use of terms as defined is critical to development of nursing knowledge. These concepts should be incorporated into nursing-related research to evaluate their usefulness to nursing. Alignment of this concept with relevant theories should be critically examined.

Keywords

concept analysis; exposure; environmental health; nursing; knowledge development

INTRODUCTION

The aim of this study was to identify an essential conceptual definition of exposure and discuss ways of measuring this concept in environmental health nursing. Exposure is strongly related to the concepts of environment, humans and health - all phenomena of central importance to environmental health nursing and nursing science in general (Fawcett & Malinski 1996). The concept of exposure is key to understanding the links among these phenomena.

Globally, the importance of the environment and its impact on health is well recognized. It has been estimated that environmental risk factors account for 80% of diseases regularly reported by the World Health Organization (WHO) and 25–33% of total disease burden (Prüss-Ustün & Corvalán 2006). Neurodevelopmental disorders have been reported as affecting as many as one in six children in industrialized countries (WHO 2011, Houtrow *et al.* 2014). In the United States, it is estimated that 5–20% of these disabilities are caused by toxic environmental exposures with annual projected costs to diagnose and treat these disorders at $240 billion or 2.8% of all U.S. healthcare expenditures (Grandjean & Landrigan 2006, Landrigan *et al.* 2002, Trasande *et al.* 2005). In particular, women of childbearing age are of great concern because their fetuses, infants and young children are vulnerable to the health effects associated with maternal exposures to certain environmental chemicals (Thompson & Boekelheide 2013). The concept of exposure is key to understanding how environmental factors affect health. The aim of this paper is to address this need by establishing a clear understanding and definition of this important concept.

BACKGROUND

In nursing, the importance of the environment has long been recognized, although the nature and scope of the concept and how it influences health has varied considerably over time. Despite *exposure* being the sufficient and necessary link to understanding how environmental factors affect health, *exposure* has not been defined explicitly or developed as a scientific concept in nursing.

As many have noted, Florence Nightingale introduced the importance of the environment in nursing in the mid-1800s (Watson 2004, Meleis 2005, Leffers *et al.* 2014). Ms. Nightingale (1860) believed that the environment was the fundamental cause of suffering and disease. Literally, disease came ‘out of the air’ (i.e., miasma). However, this emphasis on the environment fell out of favor with the advent of the germ theory, when biological agents - not the environment itself - were identified as the cause of disease (Koch 1884, 1893). The

'patient' became 'host' to these biological agents. Overall, *exposure* became synonymous with hazardous agents in the environment that contributed or caused disease. In the 1900s, when the interrelationship of host-agent-environment was described as an equilibrium state, disease was re-conceptualized as an imbalance or disequilibrium and no longer 'a reparative process' as described by Nightingale (Nightingale 1860 p.7). Similarly, the concept of environment became inconsequential, merely 'an entity where host and agent find themselves' (Gordon 1949 p.507). Health was defined as 'the absence of disease'.

For decades, nursing scholars limited the definition of environment to the personal environment that is, the places and objects that surrounded a person (Randall *et al*. 1984) with almost exclusive attention to the hospital or home environment. When the environment was viewed as the 'source of stimuli to which individuals respond' (Chopoorian 1986 p.40), nurses focused on adapting the patient's response to the environment rather than changing the environment. 'Health' and 'disease' were viewed more broadly on a continuous scale of well-being (Linder 1958). While the environment was recognized as a potentially positive source of support and healing, exposure maintained its nefarious association with hazardous agents and disease. In the 21st century, disease became the biological expression of exposure to disparities rooted in poverty, discrimination and the differential accessibility to healthcare resources (Krieger 2001, Hardy *et al*. 2013).

A global ecological perspective of the environment was not found in community and public health nursing literature until the mid-1990s (Neufer 1994, Tiedje & Wood 1995) despite the well-publicized environmental disasters of Love Canal, Bhopal and Chernobyl as well as The International Council of Nurses' (ICN) position statement (1986) on *The Nurse's Role in Safeguarding the Human Environment*. In the Institute of Medicine's *Report on Nursing, Health and Environment* (IOM, 1995), environmental health was recognized as an important and substantive area of nursing practice. The authors of this report encouraged all nurses to 'understand the scientific principles and underpinnings of the relationship between individuals or populations and the environment' (IOM 1995 p.5). In 2007, the American Nurses Association (ANA) published *Principles of Environmental Health for Nursing Practice*. This publication reiterated the IOM report and encouraged all nurses to integrate environmental health into nursing practice by 'taking into consideration all potential exposures' (ANA 2007 p.27). While the importance of the concept of exposure was acknowledged, the essential nature of the concept remained elusive.

METHODOLOGY

Kim's (2010) first level analytics were employed to develop a definition of exposure for use in environmental health for nursing. This approach included a critical evaluation of existing definitions by combining prior understanding of a phenomenon of interest with analytical rigor to clarify and refine a theoretically and potentially measurable concept. It draws on Reynolds' (1971) guidelines for evaluating concepts, including the abstractness of existing definitions, the level of inter-subjectivity of meaning (e.g., the extent to which there is agreement among scientists as to the definition and its congruence with the phenomenon to which it refers) and the definition's measurability. This approach began with a comprehensive review of the scientific literature.

Data sources

Authors identified definitions of exposure in the context of environmental health and nursing through chronological reviews of the nursing science literature using CINAHL (1980–2015) with keywords (exposure, environmental/occupational health, concept) present in the abstract yielding 379 citations. A search in ProQuest Dissertations and Theses (1980–2015) with keywords *exposure* in the abstract and *nursing* as a department resulted in 107 dissertations. After reading each abstract to determine if exposure was defined or used as a concept in an environmental health context, 108 articles and 14 dissertations were reviewed by each author independently to: 1. identify explicit or implicit definitions of exposure; 2. compare and contrast essential meaning that was articulated; and 3. ascertain whether there was alignment between definition and measurement. (Table 1.) Subsequently, the authors met for in-depth discussions of the analyses until agreement was reached on the level of inter-subjectivity of existing definitions, major points of contrast and points needing further clarification or inclusion in a refined definition.

Additionally, existing definitions and measurements of exposure were reviewed from five disciplines central to environmental health: occupational (industrial) hygiene, exposure science, epidemiology, toxicology and medicine. A search of PubMed with keywords (exposure, environmental/occupational health, concept, specific discipline) yielded 550 articles. A search of Sociological Abstracts with keywords (exposure, environmental/occupational health, concept) and (exposure, boundary/crossing) present in the abstract produced 241 articles. After the first author scanned each abstract to determine if exposure was defined or used as a concept in an environmental health context, 272 articles were retained for detailed analyses. A broad search of the Internet using the keywords (dictionary, definition, exposure) was conducted for select U.S. government and professional organizations as well as international multidisciplinary publications revealed another 33 documents for review (Table 1). Also, hand searches were conducted of discipline-specific textbooks, dictionaries and handbooks (Supplemental Table 1.) Steps of analysis conducted for the nursing science literature were repeated.

RESULTS

The word *exposure* is used most frequently in nursing as an everyday word. In the Merriam-Webster and Oxford dictionaries, *exposure* has been referred to as ‘a state or condition; the action of being subjected to any external influence’; and even as ‘a definite quantity or amount of something (as in dose).’ These definitions succinctly summarize the challenges in defining exposure for environmental health nursing since it is used to describe a (static) condition, a unit of measure and equated erroneously to dose.

In nursing education

Since at least 1980 (CINAHL’s inaugural year), the term *exposure* has been used in the nursing education literature to mean providing information and/or experiential learning opportunities for nursing students or practicing nurses (Bloomfield *et al.* 2015, Johnson 2015). Similarly, *exposure* has been used in the nursing practice literature to mean providing patients information about specific interventions and therapies (Yamagishi *et al.* 2012, Jones

et al. 2004). In these contexts, 'exposed' was equivalent to 'increased awareness' or 'informed action' thus, part of information processing.

In environmental health nursing

The term *exposure* has been used in multiple and often quite confusing ways in environmental health nursing. Rather than actually defining the essence of exposure, the term was used to identify pre-conditions (antecedents), attributes and potential consequences.

With respect to preconditions (antecedents), *exposure* was used to refer to the presence of hazards in the environment as in 'hazardous exposures' (Grady *et al.* 1997, Larsson & Butterfield 2002, Rogers & Cox 1998, Shaffer 1995); and the places where exposures occur as in 'occupational' or 'residential' exposures (Gilmore 1990, King & Harber 1998). The use or presence of a hazard in the same environment as a target was identified as a 'source', 'risk', or 'potential for exposure' (Beitz & de Castro 2010, Chaudrue 2013, Gilden 2010).

As an attribute, the term *exposure* was classified by time and/or frequency as in 'short-term, long-term, acute, chronic, cumulative, or life-long' exposures (Edmondson & Williamson 1998, McPhaul & Lipscomb 2005). Also, *exposure* was used to refer to a pathway or route (Lipscomb & Sattler 2001, IOM 1995). In one study, the term 'pathways to exposure' was used erroneously in context when the term 'routes of entry' would have been more accurate (Samuel-Nakamura 2013). 'Pathways to exposure' refers to the fate and transport of agents in media while 'routes of entry' pertains to the ways an agent gains direct access to a target (Agency of Toxic Substances and Disease Registry ATSDR 2005). In some research studies, *exposure* served not as a separate concept but as an integral part of the nursing process as in 'exposure assessment' or 'exposure history' (Sattler et al. 2006, Sattler et al. 2004). Similarly, others described a specific target population to be at-risk for exposure to a particular health problem (Sattler et al. 2008, Shelton 2009).

In terms of consequences, a third of the researchers' articles reviewed for this article described adverse consequences of exposure (i.e., symptoms or disease) rather than exposure *per se* (Nnoli 2011, Rogers *et al.* 2009). *Exposure* was referenced by degree of severity as in 'potential or excessive toxic exposure' (Sattler & Lipscomb 2003, Tiedje & Wood 1995) or used only if circumstances related to hazardous levels of toxic pollutants (Sattler et al. 2008). *Exposure* was described in terms of adverse health outcomes and posing a threat to human health (ANA 2007); causing a disease, having an impact on a condition, or adversely affecting health (Rogers 1994). Ascribing only negative health outcomes to exposures is limiting, as it does not allow for exposures that result in no effect or any health benefit. Categorizing agents as only harmful is not good theoretical thinking. Pharmaceuticals are chemical agents - are they not beneficial?

Only two explicit definitions of exposure were found in the nursing literature. In ANA's *Strategies* (ANA 2007), exposure was narrowly defined as a 'chemical exposure': 'contact with a chemical compound present in air, water, food, soil, dust, or other environmental media that might result in a change in health status' (p.35). This definition focused on only one category of agent (i.e., chemical). Also, it did not separate the definition or existence of

exposure from its impact - a necessary distinction when empirically examining the effect of an exposure. The advantage of this definition is that it did focus on *contact* as an essential component of the definition of exposure. Shendell and Pike-Paris (2007, p.180) provided a more general definition: 'exposure requires contact between a target and one or more agents, in one or more environmental media, by one or more defined pathways, at one time or over a period of time'. While this definition is phrased as a causal statement, it focuses on *contact* as a major component of the concept. Additionally, it implies that *exposure* is actually a process (and not a state) where contact is made between a target and an agent in a specific environmental context. While these two explicit definitions did not provide an adequate and complete definition of exposure, *contact* was identified as an essential component of exposure and ascribed to be part of a larger process occurring over time. To gain a greater sense of clarity and definition, the literature review was extended to include environmental health related disciplines.

Explicit and implicit definitions of exposure in other relevant disciplines

Existing definitions and measurements of exposure were reviewed from five disciplines central to environmental health: industrial/occupational hygiene, epidemiology, medicine, toxicology and exposure science (Table 2). While the search was not very helpful in identifying one unifying definition, the findings were enlightening. It became clear that historically, the concept of exposure has been implicitly defined in accordance with each discipline's lens.

In three of these disciplines (industrial/occupational hygiene, epidemiology and medicine), the focus was on a causal agent or condition. These disciplines did not define nor measure exposure but assumed that exposure had already occurred prior to pathogenesis. The remaining two disciplines (exposure science and toxicology) viewed exposure as a process rather than a state. However, exposure science represented this process as two distinct concepts (external and internal exposure) rather than two phases of a single process or concept. In toxicology, it was acknowledged implicitly that there were phases to exposure, as recognition that contact may or may not result in an agent crossing a barrier or boundary.

One explicit interdisciplinary definition of exposure was found. It was developed by a working group under the auspices of the World Health Organization, the United Nations Environment Programme and the International Labor Organization. They defined *exposure* as 'the *contact* between an agent and a target with contact taking place at an exposure surface over an exposure period (time) by an *exposure route*' (International Programme on Chemical Safety 2000, p.21). This definition is clouded by its focus on measurement and not definition. Although the essence of exposure was clearly described as a process involving contact between an agent and target in the environment followed by a route of entry, an explicit definition of exposure with a high level of inter-subjectivity remained elusive.

Defining exposure

Based on the above analysis of the literature, the following definition of exposure is proposed:

> **Exposure** is a process involving three phases: 1. contact is made between a target and one or more agents in the same environment; 2. the agent accesses the target by one or more routes of entry; and 3. the agent enters the target by crossing a barrier or boundary.

Defining exposure as a process reflects the dynamics of what happens to the agent after contact. The three phases can be conceptualized as 'contact, entry and crossing'. This review of the scientific literature (Table 2) found considerable consensus in using 'contact' in the definition of exposure, rather than being a 'condition of … or subjected to …' Typically, 'routes of entry' encompass inhalation, ingestion, dermal absorption and injection of chemical or biological agents (IPCS 2000, Zartarian *et al*. 2005). Expanding this list to include whole or partial body segments and experiential/sensory input provides congruency with physical, mechanical and sociocultural agents, respectively. Exposure science and toxicology recognize that contact may or may not result in absorption of chemical, physical or biological agents. For absorption to occur, these agents must cross a barrier. Absorption barriers include the skin, respiratory tract lining and the gastrointestinal tract wall as well as personal protective equipment (IPCS 2001, National Research Council NRC 1991, Zartarian *et al*. 2005). Following contact, a mechanical agent transfers its kinetic and/or potential energy to the target (Cromwell 2013). This transference could be comparable to crossing a barrier. Those concerned about sociocultural agents speak of human boundaries rather than barriers. A 'boundary' refers to limits or separation of an individual's intellect and emotion (Marotta 2008). Metaphorically, crossing a boundary is expressed as 'crossing a bridge' or 'opening a door' to cultural, social, political and economic conditions (Simmel 2007). There remains much discussion about how this happens (Marotta 2008).

This proposed definition of *exposure* is congruent with the WHO's definition of environmental health: 'comprising those aspects of human health, including quality of life, that are determined by physical, chemical, biological and psychosocial factors in the environment. (It) refers to the theory and practice of assessing, correcting, controlling and preventing those environmental factors that potentially affect the health of present and future generations' (WHO 1993). Additionally, the following definitions of target and agent were refined to be congruent with this proposed definition.

A 'target' is defined as a biological entity, population, subpopulation, organ system, subsystem or system component capable of compensatory response and adaptation to agent(s) in the environment (Dubos 1980, Zartarian *et al*. 2005). While nursing focuses on the human as its target of concern, a non-human biological entity may act as an intermediary for an agent by facilitating contact with a human (e.g., mosquito and malaria). Therefore, it is appropriate to use the broader term *target* as opposed to *human*.

An 'agent' is defined as an entity or stimulus that exists in the environment, irrespective of its potential to be beneficial, hazardous, a stressor or a perturbation. Exposure science defined an agent as 'any entity, stimulus or condition that exists in the environment' (Turner et al. 2003 p.8074, Zartarian *et al*. 2007 p.58). WHO (1993) referred to agents generally as factors. Categories of agents include: chemical, physical, mechanical, biological and sociocultural (Table 3). Synonyms used for potentially harmful agents include toxicant (e.g.,

chemical agents), stressor (e.g., physical agents), hazard or stressor (e.g., mechanical agents), toxin (e.g., biological agents) and stressor (e.g., sociocultural agents). Environmental agents should include a broader categorization of agent to encompass sociocultural factors. This would be congruent with epidemiological models that tie poverty and racism to biology and health (Krieger 2001). Epidemiology and medicine use of the term 'causal agents' to infer all agents have a negative impact on health. As stated earlier, categorizing agents as only harmful is not good theoretical thinking. Even the cognitive theory of stress and coping was modified to accommodate positive psychological states (Folkman 1997). The USEPA National Exposure Research Laboratory addresses both positive and negative stressors when assessing cumulative risk (USEPA 2015). Therefore, the above definition allows for an agent to have either a positive, neutral, or negative impact on health.

Measuring exposure

To identify agents and describe potential sources of exposure, researchers have used descriptions derived from environmental exposure histories, activity diaries, interviews and surveys/questionnaires (IPCS 2000). Healthcare professionals have employed two different mnemonics (IPREPARE and CH2OPD2) as prompts to inquire about environmental hazards and as reminders to educate and provide information to clients with respect to environmental health and hazards. The first mnemonic, IPREPARE was recommended by ATSDR and the Alliance of Nurses for a Healthy Environment (ANHE): Investigate potential exposures, Present work, Residence, Environmental concerns, Past work (including military service) and Activities (i.e., outside of work or school including recreation, hobby, residence-related activities) (Paranzino et al. 2005). The second mnemonic, CH2OPD2 was recommended by the Ontario College of Family Physicians: Community, Home, Hobbies, Occupation, Personal habits, Diet and Drugs (Marshall et al. 2002). Typically, an environmental health history assumes that contact took place. Documenting an environmental health history is rarely a routine component of primary care. It is employed only when there is suspicion that something in the environment may have caused the disease (Paranzino et al. 2005).

While there is no one measure for exposure *in toto*, there are indirect and direct indicators of one or more phases of this process. To facilitate understanding of the description that follows, Table 4 outlines measurement of childhood lead exposures by phase.

Phase 1: contact

To establish the amount of contact that has been made between an agent and target, researchers have measured the concentration of the agent, the area of the surface contacted and the time over which the contact occurred with respect to duration, frequency and timing.

Concentration—Often, exposure is estimated indirectly by identifying commonalities in function and distance from the agent (Nicas & Jayjock 2002). Exposures from sources remote or unknown are more difficult to assess. When agents are suspected or known, an 'exposure assessment' estimates the magnitude, duration and timing of the exposure (USEPA 2014). This type of exposure assessment assumes that the concentration of the agent generated from each source is constant for a specified duration of time (Zartarian *et al.*

1997). Chemical (e.g., lead) and biological agents (e.g., Zika virus) are measured as a concentration in one or more media source (e.g., air, water, soil, food) (IPCS 1999) or modes of transmission (e.g., direct or indirect contact). Physical agents are measured in terms of power (as a rate) given a specific wavelength on the electromagnetic spectrum (frequency) and activity (ionizing radiation). Mechanical agents are measured as kinetic and/or potential energy (Institute of Physics 2012). There are numerous active and passive devices available to measure the concentration of an agent at the point of contact with the target (IPCS 2000).

Surface—A surface on a target where an agent is present; aka contact surface (Zartarian *et al*. 2007 p.57). There are several methods available to estimate body surface area (Knaysi *et al*. 1968, Mosteller 1987). Personal protective equipment acts as a barrier to absorption by decreasing the surface available for measuring contact, provided the equipment selected is appropriate protection for the specific agent and worn properly.

Time Period—The time of contact between an agent and a target (Zartarian *et al*. 2007). While duration of exposure is more critical for chemical agents with shorter half-lives, it is less critical for those with longer half-lives (e.g., lead, methylmercury, polychlorinated biphenyls or PCBs). While adding a time-step loop may provide insight into intra-individual variation, it does not address inter-individual variation adequately. A large population sample is required to compensate for these variations (Price & Chaisson 2005).

Duration—The length of time over which continuous or intermittent contact occurs between an agent and a target (IPCS 2000, Zartarian *et al*. 2007). Duration may be referred to as short-term (e.g., less than one month) or long-term (i.e., months to years). A pre-school aged child's exposure to lead in the home is considered long-term (e.g., five years).

Frequency—The number of contacts between an agent and target over time (Zartarian *et al*. 2007). Frequency may be referred to as acute (e.g., once or twice) or chronic (e.g., all day). A school age child's exposure to lead in the school is considered chronic (e.g., 32 hours per week).

Timing—There are structural and functional windows of vulnerability (e.g., fetal through early childhood development) during which exposures to agents (e.g., lead) have the potential to alter physical and physiological development as well as psychological and social behavior permanently (Wilson, 1973).

Phase 2: routes of entry

Methods to identify and describe routes of entry for all categories of agents were identical to those used in phase one (i.e., activity diaries or direct observations). There are no measurements for routes of entry *per se*. More specifically, once contact is confirmed, identification of routes of entry is deduced through characterization of an agent's properties and identification of the contact media. For example, if the chemical or biological agent is in the air, then these agents' potential routes of entry are inhalation and/or dermal absorption. If the agent is present on a surface that the target contacts, the route of entry will be dermal absorption. If the agent is present in food or water, then the route of entry is ingestion.

Secondary ingestion is associated with activities such as smoking, applying cosmetics and touching contaminated surfaces and other objects. Hand-to-mouth is a common route of entry particularly among infants and small children. Punctures in the skin indicate injection. Additionally, the mucous membranes, eardrum and eyes are potential routes of entry. For example, if the eardrum is not intact, it presents a route of entry for some airborne agents. Whole and/or partial body segments would identify points at which mechanical and physical agents exert a force.

Phase 3: crossing a barrier or boundary

Methods to measure before crossing occurs included energy transference and bioavailability for mechanical/physical and chemical agents, respectively. Energy transference can be calculated for mechanical and physical agents. Bioavailability is an estimation of the rate and extent to which an agent is available to serve as a substrate, bind to a specific molecule, or participate in biochemical reactions in a target tissue once it crosses a barrier (NRC 2006; USEPA 2015). This computational-based calculation estimates the bioavailability of an agent and is expressed as a percentage. Methods to measure *after* crossing include specific biomarkers. For biological agents, a titer assay or load is calculated (LaBarre & Lowy 2001).

Biomarker of exposure—Biomarkers are biochemical, molecular, genetic, immunologic or physiologic indicators of a recent or previous event in a biological system (NRC 2006). A biomarker of exposure may be an agent, its metabolite, or the product of an interaction between an agent and a molecule or cell that can be measured in a compartment (e.g., blood, tissue, organ, placenta, etc.) of a target (NRC 2006, Wallace 2007).

The presence of a biomarker of exposure confirms that contact and crossing has occurred. However, a biomarker measures more than just exposure. Biomarkers reflect the relationship between an agent and the target's body burden as a function of ongoing adaptive processes at any given instant in time (Zartarian *et al.* 2007). As a result, these processes confound the measurement of exposure.

Each of these existing measures align well with one or more phases of the exposure process with the exception of routes of entry where no measurement was identified. The degree to which a target lives safely and healthy depends largely on its exposures to agents in the environment and the timing of those exposures. Since health outcomes are consequences of these exposures, assessment and measurement of a lifetime of exposures is essential to nursing practice. *Exposome* is a term that refers to the measurement of all exposures in a lifetime - womb to tomb (Wild 2005, 2009, 2011; Vrijheid 2014). Measuring the exposome in its entirety has its logistical challenges (Wild 2012). The '-omics' of this science centers on the measurement of the target's biomolecular and metabolic changes that occur as a result of the exposure process. Since environmental health nursing embraces a precautionary and primary prevention approach to practice, caution is advised regarding using 'exposome' as an operational definition for exposure.

DISCUSSION

This concept analysis provides a clearer understanding of the concept of exposure. The concept of exposure has been explicitly or implicitly defined in each of six disciplines reviewed in accordance with the lens that each discipline uses. Some definitions were broad and vague or detracted from the important role of exposure in the context of environmental health. Despite the release of seminal publications on environmental health in nursing (ANA 2007, IOM 1995), there was no consensus on the definition of exposure in the nursing literature. For example, the word exposure was used broadly in an educational context, more specifically, to provide information and experiential learning opportunities. To avoid confusion, a more appropriate synonym should be used for this application. This research emphasizes the need for clarity and separation of terms used synonymously and erroneously such as *poisoning* and *contamination* (O'Neal 2011, Green & Polk 2006, 2007, 2012). It was concluded that one must recognize and acknowledge exposure as a process with three phases: contact, route of entry and crossing a barrier or boundary.

Existing conceptual definitions of exposure were clouded by including specific elements of measurement. For this concept to be useful in nursing scholarship and research, exposure must be clearly defined *and* measureable. Existing measures align well with one or more phases of the exposure process though no measurement was found for routes of entry. Measuring the exposome in its entirety has its logistical challenges.

It is important to clarify the underlying phenomenon of the concept of exposure in environmental health. All nursing specialties support the relevancy and inclusion of the environment in research, practice and policy. As currently defined here, use of this concept should be incorporated into nursing research and practice, regardless of specialty. In this way, its usefulness to nursing can be evaluated.

Environmental health nursing is an important and substantive area of nursing practice but a relatively new nursing specialty. This analysis contributes to the body of knowledge in environmental health for nursing. Exposure is a process of human nature and living; an essentialistic concept in Kim's metaparadigmatic typology. This typology classifies phenomena and organizes theoretical elements into four domains: client, client-nurse, practice, environment from a nursing perspective (Kim 2010). In the client domain, essentialistic concepts include human characteristics, processes and experiences that are important and critical to nursing (Lundgren et al. 2009). A conceptual model is encouraged for environmental health related research in nursing that incorporates this concept. Alignment of this concept with relevant theories should be critically examined: for example Adaptation Theory (Dubos 1980) and the Environmental Health Paradigm (Sexton, Olden & Johnson 1993).

Limitations

Only articles written in English and listed in CINAHL, ProQuest Dissertations and Abstracts, PubMed and/or Sociological Abstracts online databases were used. Nurses do publish in peer-reviewed multi-disciplinary environmental health related journals. However,

it was not possible to ascertain easily whether authors in these journals were nurses. These exclusion criteria may have omitted articles pertinent to this study.

CONCLUSION

The concept *exposure* is newly defined as a process (contact, entry and crossing) in nursing. Definitions of target and agent were refined for congruency. Multidisciplinary ways of measuring exposure were identified and discussed in relation to each phase. There remains a need to develop a way to measure the full completion of the exposure process. Exposure is the sufficient and necessary link to understanding how environmental factors affect health.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Why is this research or review needed?

- The importance of the environment has long been recognized in nursing. Exposure is the sufficient and necessary link between environment and health.
- Exposure was not explicitly defined in the nursing literature.
- For this concept to be useful in nursing scholarship and research, it must be clearly and consistently defined and measured.

What are the three key findings?

- A new conceptual definition of *exposure* as a process is presented in environmental health for nursing.
- Multidisciplinary measures related to each phase were identified and discussed.
- Refined definitions of *target* and *agent* are congruent with this definition.

How should the findings be used to influence policy, practice, research and/or education?

- All nursing specialties support the relevancy and inclusion of the environment in research, teaching, practice and policy.
- Alignment of this concept with relevant theories should be critically examined.
- Exposure should be the key concept of concern when addressing environmental health issues in nursing.

Table 1

Search Parameters for Concept Analysis

Online Databases*	**CINAHL[1] 1980–2015**	**ProQuest Dissertations[2] 1980–2015**	**PubMed[3] 1980–2015**	**Sociological Abstracts[4,5] 1980–2015**	**U.S.[6,7]**	**International[6,8]**
Number of Citations	379	107	550	241	257	2,450
Exclusion Criteria: abstract						
the word “exposure” not used in the context of environmental health and nursing	271	93	--	--	--	--
the word “exposure” not used in the context of environmental health and related disciplines	--	--	433	190	242	832
Inclusion Criteria: abstract						
the word "exposure" used in the context of environmental health nursing	108	14	--	--	--	--
the word "exposure" used in the context of environmental health and related disciplines	--	--	197	75	15	18
Number of Articles/Documents Reviewed, Categorized and Analyzed by discipline/area of specialty, context, explicit definition, implicit definition, and existing measures	108	14	197	75	15	18

Keywords	**Filters**
[1]exposure, environmental health or occupational health, concept	English, peer-reviewed, human
[2]exposure and nursing (department)	English
[3]exposure, environmental health, concept, specific discipline	English, journal article, human
[4]exposure, environmental health or occupational health, concept	English, peer-reviewed, scholarly journal
[5]exposure, boundary or crossing	English, five years, peer-reviewed, scholarly journal
[6]dictionary, definition, exposure	

[7]U.S. Government and Professional Organization Websites: Occupational Safety and Health Administration (OSHA), United States Environmental Protection Agency (USEPA), Agency for Toxic Substances and Disease Registry (ATSDR), National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC), Institute of Medicine (IOM), American Nurses Association (ANA), Institute of Physics (IOP)

[8]International and Professional Organization Websites: World Health Organization (WHO), International Programme on Chemical Safety (IPCS), United Nations Environment Programme (UNEP), International Labour Organization (ILO), European Union Environment Agency (EEA), International Union of Pure and Applied Chemistry (IUPAC), International Council of Nurses (ICN)

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* Database searches were conducted in January/February 2015

Table 2

Explicit and Implicit Definitions of Exposure by Discipline

	Discipline	Explicit	Implicit
Exposure as Causal Agent	**Industrial/Occupational Hygiene**: the study of the generation, transport and distribution of contaminants within a specific environment Source: Banerjee *et al.* 2014	NA	Exposure is categorized by the degree to which contaminants are controlled in the environment i.e., severe, moderate, minimal Source: Vadali *et al.* 2009
	Epidemiology: the study of the distribution and determinants of health-related events in populations Source: World Health Organization 2015	*Exposure Group:* a population that has been exposed to a causal agent of disease or health state, or possesses a characteristic that is a determinant of a specific health outcome Source: Centers for Disease Control & Prevention 2012a	1. interrelatedness of host, agent and environment 2. presence/absence of risk factors 3. interaction between subject and socioeconomic factors Sources: Gordon 1949, Susser & Susser 1996, Krieger 2001
	Medicine: the science and practice of the diagnosis, treatment and prevention of disease Source: Mosby 2009	a condition of being unprotected or subject to some detrimental effect or harmful condition Source: Mosby 2009	1. prepathogenesis begins with the host's exposure to the etiological agent 2. categorization of exposures into "toxic syndromes" Sources: Leavell & Clark 1958, Klaassen & Watkins 2003
Exposure as Process	**Toxicology**: the study of the nature, effects, and detection of poisons Source: International Union of Pure and Applied Chemistry 2007	1. a concentration that reaches the target 2. a process by which an agent becomes available for absorption by target 3.the sum of the electrical charges of all ions of one sign … as in x- or gamma radiation Source: International Union of Pure and Applied Chemistry 2007	NA
	Exposure Science: the study of human contact with chemical, physical, or biological agents occurring in the environment Source: National Research Council 2012	*External* exposure: the contact between an agent and a target (e.g., human) that takes place at an exposure surface over an exposure period *Internal* exposure: contact between an agent or a receptor on level of physical or biologic organization past the external boundary toward the target site Sources: Zartarian 2007; National Research Council 2012	NA
	Government	**Explicit**	**Implicit**

Interdisciplinary	Occupational Safety and Health Administration (OSHA)	*Exposed Employee*: subjected to a chemical that is a physical or health hazard, and includes potential (e.g., accidental or possible) exposure *Subjected*: includes any route of entry (e.g., inhalation, ingestion, skin contact or absorption). Source: 29CFR1910.1200c	NA
	Agency for Toxic Substances and Disease Registry (ATSDR)	contact with a substance by swallowing, breathing, or touching the skin or eyes Source: ATSDR 2009	NA
	International Programme on Chemical Safety (IPCS)	the contact between an agent and a target with contact taking place at an exposure surface over an exposure period (time) by an exposure route Source: IPCS 2000	NA

Table 3

Categories of Agents and Measurements of Exposure by Agent Category

Category	Chemical[1]	Physical	Mechanical	Biological	Sociocultural
	Health-Related Characteristics	Energy/Electro-Magnetic	Mechanical Energy	Allergen	Stressors
	Acute Toxicity	Electricity	Vibration	Bacteria	Emotional Conflict
	Skin Corrosion/Irritation	Ionizing Radiation	Ergonomics	Endotoxin	Interpersonal Strain
	Serious Eye Damage/Irritation	X-Rays	Posture	Envenomation	Lateral Violence
	Respiratory/Skin Sensitization	Gamma Rays	Position	Fungi/Mold	Work-Family Conflict
	Germ Cell Mutagenicity Categories 1 & 2	Radon	Pressure	Malignant Cells	Socioeconomic Stressors
	Carcinogenicity	Non-Ionizing Radiation	Repetitive Motion	Mycobacteria	Shift Work
	Reproductive Toxicity	Ultraviolet (UV)	Manual Materials Handling	Parasite	Violence/Terrorism
	Specific Target Organ Toxicity Single & Repeated Exposures	Laser	Impact	Recombinant	Organizational Culture
	Aspiration Hazard Categories 1 & 2	Infrared (IR)	Object	Rickettsia	Race-Ethnicity
	Hazardous to Aquatic Environment Hazardous to Ozone Layer	Radio Frequencies (RF)	Surface	Virus	Acculturation
	Physical-Related Characteristics	Sound	Confined Space	Wood Dust	
	Explosive	Environment			
	Flammable Gas, Liquid, Solid Chemically Unstable Gas	Temperature (heat/cold)			
	Combustible	Atmospheric Pressure			
	Self-Reactive Substance or Mixture				

Category	Chemical[1]	Physical	Mechanical	Biological	Sociocultural
	Self-Heating Substance or Mixture				
	Oxidizing Gas, Liquid, Solid				
	Gas Under Pressure, Aerosol				
	Pyrophoric Liquid, Solid				
	Organic Peroxide				
	Water-Reactive Substance or Mixture				
	Corrosive to Metals				
	Cryogen				
Measurement	**Chemical**	**Physical**	**Mechanical**	**Biological**	**Sociocultural**
Phase 1 contact concentration, surface, time period (duration, frequency, timing)	*x* concentration of agent in *y* quantity media	power given a specific wavelength on the electromagnetic spectrum; activity (radiation)	kinetic energy, potential energy	*x* concentration of agent in *y* quantity media; modes of transmission	
Phase 2 routes of entry	activity diaries, direct observations				
Phase 3 crossing barrier, boundary	bioavailability biomarkers of exposure	energy transference biomarkers of exposure	energy transference biomarkers of exposure	titer or load biomarkers of exposure	biomarkers of exposure

[1] United Nations, 2013

Table 4

Assessment of Childhood Lead Exposures

Phases	Details	Notes
Potential Sources of Exposure	air	emissions
	water	aerial deposition and potable water delivery systems
	soil	aerial deposition and naturally occurring deposits
	food	uptake from contaminated soil
	dust	aerial deposition, flaking lead paint, lead in soil
	historical legacies	lead in paint and gasoline, industrial discharges
	residence, school, industry, neighborhood,	constructed before 1978, nearby hazardous waste sites
	global pollution	country of birth; years before immigrating to U.S.
	imported from countries where no ban on lead	imported toys, jewelry, personal care products, medicines
	occupational	family members' occupations, hobbies; lead contaminated clothes, objects
Agent Category	Chemical	
Specific Chemical Agent	Lead (Pb)	persistent and pervasive global pollutant
Phase 1		
contact		
concentration	in air, water, soil, food, contaminated surfaces	parts per million (ppm), parts per billion (ppb)
surface	hands, mouth, gastrointestinal wall	
time period	dates (specify)	
duration	chronic: months to years (specify)	pre-school age: continuous if source is residential, neighborhood
frequency	intermittent to continuous	school age: intermittent if source is school
timing	fetus and child ≤ 5 y/o most vulnerable	neurodevelopment, neurobehavioral development
	intergenerational transference	passes through placenta and breast milk
Phase		
routes of entry		
	inhalation, ingestion (primary)	air pollution, contaminated drinking water/food
	ingestion (secondary)	touching contaminated surfaces - hand-to-mouth transmission
Phase 3		
crossing barrier, boundary		
barrier	gastrointestinal wall	
bioavailability	49% on average (Luo et al. 2012)	dietary calcium and phosphate decreases bioavailability (Zia et al. 2011)
biomarker of exposure		
	xenobiotic measurement: lead in blood (μg/dL)	5 μg/dL reference blood level for children ≤ 5 years old (CDC 2012b,2012c)