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Concept clarification of neonatal neurobehavioural organization

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Abstract

Aim—This paper is a report of a concept analysis of neonatal neurobehavioural organization for healthy full-term infants.

Background—The neonatal period is an opportune time for researchers and clinicians to assess and intervene for optimal neurobehavioural organization. Yet there is inconsistency and lack of clarity in a scientifically grounded definition of neonatal neurobehavioural organization. Clarification of the concept will strengthen research findings that influence practice for optimal infant development.

Method—A concept analysis of the literature between 1939 and 2007 ($n = 57$) was conducted using Penrod and Hupcey's principle-based concept analysis and Morse's concept clarification.

Findings—The concept analysis within and across multiple disciplines revealed: (1) a view of the concept as a holistic phenomenon with multiple dimensions; (2) no agreement on the ideal instrument to operationally define the concept; and (3) consistency in implied meaning, but great variability in terminology. Neonatal neurobehavioural organization was defined as the ability of the neonate to use goal-directed states of consciousness, in reciprocal interaction with the caregiving environment, to facilitate the emergence of differentiating, hierarchical, and coordinated neurobehavioural systems, with ever-increasing resiliency and capacity to learn from complex stimuli.

Conclusion—A clear conceptual definition will help the international community to communicate effectively within and between disciplines and to apply evidence-based research findings. It will encourage the development of valid and reliable instruments to capture the concept's multiple dimensions and direct attention to the infant's experience, which sculpts early neurobehavioural organization.

Keywords

behaviour; concept analysis; development; infant; neonatal neurobehavioural organization; neonate; newborn; nursing

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Author contributions AB was responsible for the study conception and design and AB and RL were responsible for the drafting of the manuscript. AB and RL performed the data collection and data analysis. RWT made critical revisions to the paper and supervised the study.

Introduction

In the neonatal period (the first 28 days after birth) there is a sensitive and dynamic unfolding of neurobehavioural organization (NBO) unique to the neonate (Blackburn 2005). NBO is a mature multidimensional construct and includes an individual's ability to interact with the environment while maintaining internal stability. This internal stability is the foundation from which the neonate is able to socially interact and learn from the environment. The neonatal period offers an opportune time for researchers and clinicians to assess and intervene for optimal infant health. Yet, within and across disciplines, there is inconsistency and lack of clarity in a scientifically grounded definition of neonatal neurobehavioural organization. The aim of this paper is to analyse and clarify the concept of neonatal neurobehavioural organization (NNBO) for healthy full-term infants.

Method

Concept analysis method

Principle-based concept analysis by Penrod and Hupcey (2005) is a robust method for the advancement of a concept. Penrod and Hupcey emphasize two distinct elements within concept analysis. First, the existing state of science must be analysed and clarified using a multidisciplinary approach. Second, advancement of the concept occurs through the synthesis of new insights. Principle-based concept analysis expands upon earlier work of Hupcey *et al.* (Morse *et al.* 1996, Hupcey *et al.* 2001). The analysis is guided by four principles: epistemological, pragmatic, linguistic and logical. Penrod and Hupcey (2005) describe the epistemological principle as an exploration of what is known about the concept, and whether the concept is well-defined and differentiated from other concepts in the literature. They describe the pragmatic principle as an evaluation of how well the concept has been operationalized, and whether it is applicable or useful for clinical practice and research. To address the linguistic principle, Penrod and Hupcey ask analysts to assess whether the concept has been used consistently and appropriately, and if the concept becomes more abstract or limited depending upon theoretical context. Finally, they describe the logical principle as an analysis of the integrity of the concept when positioned with similar concepts or elements within the concept. That is, they suggest asking whether the concept allows for multiple relationships without getting lost in translation.

Morse *et al.* (1996) suggested that concept analysis begins with assessing a concept's level of maturity. When a concept appears to be mature within a large body of literature, yet is associated with inconsistent and competing assumptions or variables, then quantitative and/or qualitative research may be used effectively in concept clarification. Clarifying a concept requires a thorough familiarization of the literature to recognize underlying values and assumptions common to the concept under review (Morse 1995). Based on these values and assumptions, attributes can then be identified and synthesized.

Data sources

Selection of data sources for a concept analysis can be driven by an unconsciously assumed theoretical framework or by a consciously identified theoretical framework that is either implicitly or explicitly defined (Paley 1996). We identified an implicit theoretical framework, the infant's complex behavioural repertoire, to provide structure to the selection of the literature review. Recognition of the infant's complex behavioural repertoire was developed by experts across multiple disciplines over several decades, but can be first traced to the 1930s with the publications of McGraw (1939b, 1943) and contemporaries (Gilmer 1933, Pratt 1935). Their views were in contrast to the prevailing theoretical perspective that the infant was a passive recipient of environmental stimuli. It was not until the 1970s that there was an acceptance of

infants as active participants in sculpting their NBO. This paradigm shift integrated two approaches to infant assessment: neurological (Andre-Thomas & St.-Anne Dargassies 1960, Prechtl & Beintema 1964) and behavioural (Graham 1956, Rosenblith 1959). This integration in the literature of neurology and behaviour has created a more broad and holistic view of the infant's NBO.

The literature search was completed in two phases. Initially the search was conducted within the three most appropriate electronic databases (Ovid Medline, CINAHL and Psyc-INFO) from 1970 to 2005. The search was limited to the English language and human studies. The keyword 'neonatal neurobehavioural organization' was initially used as the search term. This resulted in only a handful of articles; therefore the search was expanded to include various combinations of related keywords: neonatal, newborn, infant, behaviour, organization, neurobehaviour, behavioural response, behavioural competence, state regulation, central nervous system and development. Papers were deleted if they were limited to a narrow dimension of the concept, such as habituation, or if the concept was used only as a measurement outcome without contributing depth and scope. Additionally, papers were rejected if limited to issues specific to preterm, compromised or pathologically developed infants since the focus was the normal NBO of the healthy, full-term neonate. It became apparent that certain authors were frequently cited for their contribution to development of the concept of NNBO. Thus, a second literature search phase was refined to include the work of highly influential authors.

The final data set of the literature reviewed included 48 articles and nine books from 1939 to 2007. Authors of the methodologies used for this concept analysis do not explicitly state a desirable data set size. Rather, Penrod and Hupcey direct that the 'literature selection must be conceptually driven, not statistically driven' to accurately represent the state of the science (2005, p. 407). Our literature selection represents a small data set owing to our commitment to include only researchers who contributed to the scope and depth of the concept.

Results

Epistemological principle

The epistemological principle was analysed in three ways. First, we synthesized contributions from influential researchers in the fields of psychology, developmental psychology, medicine, and nursing (see Table 1). Second, we summarized the major contributions from each discipline. Exclusive contributions from within a single discipline were difficult to identify, as researchers concurrently and conjunctionally developed the concept. Finally, we extracted shared attributes from the literature using Morse's method of concept clarification (1995) to provide a clear definition of NNBO.

Summary of each discipline's contribution to defining the concept—Investigators in the field of psychology and developmental psychology established the foundation of our understanding of NNBO. They have recognized that infants are active participants in their own development. An infant's individual development is sculpted by sensory experience and thus intrinsic to NNBO. NNBO unfolds in a hierarchical manner as the infant's capacity for stability increases in the midst of a constantly changing environment. An individual's NBO is based on the ability to self-regulate an internal locus of control and reciprocally interact with external environmental stimuli.

In contrast to the holistic nature of NNBO found in the disciplines of psychology and developmental psychology, investigators in the field of medicine have emphasized the infant's neurological integrity as the basis of NNBO. The paediatrician, T. Berry Brazelton, was the first to articulate to the general public that NNBO was a multidimensional holistic phenomenon, and to encourage a multidisciplinary approach to research. Brazelton and colleagues led the

paradigm shift towards recognizing the competent infant as a determinant in research and practice.

At the forefront of translational research, researchers in the field of nursing have investigated dimensions of NNBO as they apply to clinical practice. Not only have nursing researchers contributed to the understanding of how altered NBO in at-risk infants has immediate and long-term effects on developmental trajectories, but they have also designed interventions to support optimal NNBO. Interventions have included White-Traut's (White-Traut & Nelson 1988, White-Traut *et al.* 2002b) auditory, tactile, visual and vestibular stimulation; Thoyre *et al.* (2005) developmental profile of feeding readiness; Pridham *et al.* (2005) guided participation on feeding competencies; Censullo's (1994, Horowitz *et al.* 2001) interaction coaching to promote mother–infant interaction and Ludington-Hoe *et al.* (1991, 2006) research on skin-to-skin contact (*i.e.* kangaroo care).

Attributes of the concept—Using Morse's method of concept clarification (1995), we found five attributes that were pervasive throughout the data set. The first attribute is the dynamic nature intrinsic to the concept. There is a reciprocal interchange of information between neonates and their caretaking environment. NNBO is characterized by rapid developmental change. With NNBO, there is never a finished product, but rather an ever-evolving fluid process.

Second, interaction with the environment is not random; therefore there is an attribute of selection and purpose. Neonates seek the stimuli they need to further their neuronal and behavioural development. Neonates influence their caretakers by communicating a wide variety of cues to elicit the behaviour they seek. When the neonate initiates a need and receives the attention desired, cues are sent to the caregiver that may induce a sense of satisfaction; therefore selective biobehavioural feedback loops serve to encourage continued reciprocity between neonate and caregiver.

The third attribute is that the neonate innately coordinates sensory, autonomic, motor, behavioural state regulation and social interaction systems. Coordination of these systems develops in a hierarchical manner, with an open exchange of information that facilitates more and more complex organization. Social interaction is deemed the highest level of organization whereby the neonate is able to attend and interact with the caregiving environment.

Fourth, the neonate has the ability to recover from the physiological cost of positive and negative stimuli; therefore there is an attribute of resiliency. The neonate responds to stimuli with states of consciousness that either encourage or discourage interaction. If a stimulus is overtaxing and the neonate's state discourages interaction, then the neonate must reorganize before a stimulus can be processed effectively. Challenging experiences with new stimuli encourages growth and differentiation of neurons and their synapses.

The fifth attribute, which builds upon the preceding four, is the recognition that the neonate has an ever-increasing capacity for stability through change. Living systems develop within an optimal range of external and internal conditions that are constantly changing. Thus, as the neonate's multilevel capacity for stability increases in the midst of changing conditions, developmental maturation is enhanced.

In summary, the shared patterns of attributes for NNBO include (1) a dynamic reciprocal process of neonatal interaction with the caretaking environment, (2) goal-directed behaviour that elicits environmental stimuli to fuel inner neuronal and behavioural development, (3) coordination of multi-systems that emerge in a hierarchical manner, (4) resiliency to recover

from the physiologic cost of stimuli, and (5) a maturational capacity for stability through change.

Definition of the concept—Synthesis of the shared attributes of NNBO may be clarified into one definitional sentence. NNBO is the ability of the neonate to use goal-directed states of consciousness, in reciprocal interaction with the caregiving environment, to facilitate the emergence of differentiating, hierarchical and coordinated neurobehavioural systems. Maturation of NNBO is evidenced by the neonate's ever-increasing resiliency and the capacity to learn from complex stimuli.

Pragmatic principle

Neonatal neurobehavioural organization has been operationally defined in a variety of ways. We found that there was lack of agreement in the literature within and across disciplines on the ideal operational definition. Factors that contribute to the difficulty in the measurement of NNBO include (1) the complexity of neonates as living systems, that interact bi-directionally with their environment, during a period characterized by rapid development; (2) multiple dimensions that are intrinsic to NNBO; (3) uncertain validity of an instrument's ability to predict meaningful developmental outcomes; and (4) lack of a unified view of NNBO. In the past, researchers operationalized NNBO as either the neurologic status (Prechtl & Beintema 1964) or psychological function (Graham *et al.* 1956) of an infant. Today, many researchers appreciate that NNBO spans a broad behavioural repertoire which includes neurological integrity, learning, perception and social interaction (Lipkin 2005). While past and current approaches of measuring NNBO are far too extensive to list, some salient approaches have included: (1) behavioural state regulation which serves as a critical antecedent and outcome of NNBO (Wolff 1987); (2) Brazelton's Neonatal Behavioural Assessment Scale – an excellent descriptor of a broad range of behavioural competencies but criticized for questionable predictive validity (Brazelton & Nugent 1995); and 3) nutritive sucking parameters that were first researched in the 1960s and recently resurfaced as a valid window into NNBO (Kron *et al.* 1963, Medoff-Cooper & Ratcliffe 2005). Additionally, we identified numerous multidimensional instruments specific for evaluating neurobehaviour in the fetus, preterm neonate, developmentally at-risk neonate, and older infant (Amiel-Tison 2002, DiPietro *et al.* 2002, Als *et al.* 2005, Einspieler & Prechtl 2005).

Currently, researchers in the fields of nursing, developmental neurology and physiology, physical and occupational therapy, paediatrics, and developmental psychology are contributing to our understanding of NNBO by measuring specific dimensions of this complex concept. Specific dimensions of NNBO include the measurement of sleep and alert states (Holditch-Davis & Thoman 1987, White-Traut *et al.* 2002a, Salisbury *et al.* 2005), breastfeeding behaviours (Radzynski 2005), sucking parameters (Medoff-Cooper 2005), movement patterns (Campbell *et al.* 2002, Einspieler & Prechtl 2005, Majnemer & Snider 2005), event-related potentials of auditory stimulated brain activity (deRegnier 2005) and heart rate variability (Porges 2007).

Linguistic principle

The implied meaning of NNBO is consistent among the experts in nursing, developmental neurology and physiology, paediatrics, psychology and developmental psychology. Across disciplines, there was consistency regardless of the population, contextual setting, and independent and dependent variables used to examine the concept. However, as noted in the data source section, the terminology used for NNBO is quite variable within and across disciplines. While NNBO is conceptually bound to the neonatal period, and is the normative criterion for all infants at risk (*e.g.* preterm), there is coherent integration of dimensions within NBO between the preterm period and neonatal period.

Logical principle

Researchers in nursing, developmental neurology and physiology, paediatrics, psychology and developmental psychology tend to view NNBO as a holistic phenomenon encompassing inter-related dimensions, although researchers in medicine are inconsistent in their view of the integrity of the concept. Investigators in the field of medicine also have reduced NNBO to only physiological dimensions. Predominantly, researchers across disciplines have examined specific dimensions of NNBO that integrate and define the boundaries of the concept.

From this dimension-based analysis, NNBO was determined to be a mature yet inconsistently defined multidisciplinary concept. Through this concept analysis of NNBO we have clarified the common attributes, operational measurements, linguistic terminologies and conceptual boundaries.

What is already known about this topic

- In the neonatal period (the first 28 days after birth) there is a sensitive and dynamic unfolding of development unique to the neonate.
- This is therefore an opportune time to assess and intervene to promote optimal neurobehavioural organization.
- The policy and culture of many maternal-child units demand clinicians to be task-rather than synchrony-oriented and thus there are missed opportunities to enhance neonatal neurobehavioural organization.

What this paper adds

- Inconsistent terminology, lack of a gold standard measurement, limited understanding of the concept's interplay between environmental interaction and genetic expression, and limited evidence of the concept's predictive relationship between the neonatal period and later developmental trajectories were identified in the literature.
- Neonatal neurobehavioural organization is the ability of the neonate to use goal-directed states of consciousness, in reciprocal interaction with the caregiving environment, to facilitate the emergence of differentiating, hierarchical and coordinated neurobehavioural systems.
- Maturation of neonatal neurobehavioural organization is evidenced by the neonate's ever-increasing resiliency and the capacity to learn from complex stimuli.

Discussion

Limitations of this concept clarification were identified as inherent in the process of synthesizing a manageable data source. Early researchers, who pioneered the neurological integrity of infants, were not included because of their theoretical framework where infants were viewed as passive recipients of their environment. Animal literature on NBO was not included, as it is extensive and beyond the scope of this analysis. In spite of an effort to maintain scientific rigour in selecting a conceptual driven sample, we recognized that author bias is intrinsic to concept analysis.

Several important gaps in the current state of the science were identified: (1) the unclear influence of fetal exposure to maternal medication during labour on NNBO; (2) the need for stronger evidence of the predictive relationship between NNBO and individual infant

developmental trajectories; (3) disagreement, within and across disciplines, on the ideal instrument to accurately measure NNBO; and (4) limited understanding of the neurobehavioural dimensions of NNBO and their interplay on multiple levels, from genetic expression to environmental interaction.

In the 20th century, researchers' perspectives changed from viewing the infant as passive objects of study to active participants in their own development. As a reflection of this paradigm shift, the opportunity has arisen to revisit the synchronous interplay between internal and external systems owing to a refined conceptual understanding of the dynamic forces that effect development. Additionally, experts have refined the ability to non-invasively capture multiple variables of NNBO, such as vagal tone, event-related potential, sucking parameters, mother–infant synchrony, and electroencephalogram characteristics of sleep–wake cycles. Recent technological advances in ultrasound have further contributed to understanding the continuity of development from fetus to neonate (Salisbury *et al.* 2005). The implications of the environment and the infant's unique neurobehaviour on the expression of the individual's genetic code should be considered in the advancement of this concept (Gottlieb 2001). For instance, Feldman and Eidelman model the advancement of this concept by exploring the dynamic relationship between biological dimensions of NBO and reciprocity of mother–infant interaction and the effect on future cognition (Feldman & Eidelman 2006). The development of effective interventions will be promoted by additional translational research.

Implications for advancement of the concept through clinical practice include the application of evidence-based research findings into everyday plan of care. Unfortunately, policy and culture of many institutional maternal-child units demand nurses to be task- oriented rather than synchrony-oriented (*i.e.* sleep–wake cycles, feeding readiness cues, uninterrupted mother–infant skin-to-skin contact, attention–interaction). Clinicians' ability to augment NNBO by reducing infant stress, maintaining sleep–wake cycles, promoting social-interaction during alert periods, and modifying the environment to maintain social interaction will be strengthened by this concept clarification.

Conclusion

Neonatal neurobehavioural organization is a global phenomenon that captures the essence of healthy full-term neonatal function as resilient, individualized, complex, experiential and holistic. A clear conceptual definition will aid the international community (1) to communicate effectively within and between disciplines, (2) to apply evidence-based research findings, and (3) encourage the development of valid and reliable instruments to capture the multiple dimensions of NNBO. Clarification of NNBO directs attention to the infant's experience, which facilitates sculpting of early NNBO. Nursing and allied health professionals who influence neonates' initial unfolding of NNBO must be aware of the potential impact on their future developmental trajectories. Further analysis of NNBO with premature or medically fragile infants would add to our understanding of compromised infants' ability to respond and recover from environmental stimuli. Thus development of the concept in this vulnerable population would advance clinical practice across disciplines.

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Table 1

Contributions of influential researchers

Influential researchers and their disciplines	Epistemology	Pragmatic	Linguistic	Logistic
Psychology (Trevathan & Aitken 1994, Aitken & Trevathan 1997)	At birth, the neurobiology of the brain supports the intrinsic motivation to communicate and interact, which is a critical process for furthering human development	Grounded observable behavioural literature to the brain's neurobiology	Used a related concept, Intrinsic Motive Formation (neonate's motivation to communicate and promote self-development)	The concept of Intrinsic Motive Formation is a dimension of NNBO
Psychology (Als 1982, 1991, Als <i>et al.</i> 2005)	Distinct subsystems of NNBO (autonomic, motor, state organizational, attentional-interactive, and self-regulatory) emerge in a hierarchical pattern through internal, dynamic, continuous interplay	Developed the Synactive Model of Neonatal Behavioural Organization and Assessment of Preterm Infants Behaviour. Clinical significance is to modify the environment to stabilize the premature infant's initial emerging subsystems. Goal is to support the continued emergence of organization, culminating in social interaction	Consistency in meaning and use of NNBO	The concept holds its boundaries in preterm and neonatal periods
Nursing (Anderson 1977, 1991, Gill <i>et al.</i> 1988)	Early work viewed sucking opportunities as facilitating neuromuscular coordination and behavioural state organization. Later work viewed skin-to-skin contact as supporting the coordination of physiological systems (i.e. autonomic system) and mother-infant reciprocity	Translational application of NBO. Supporting mother-infant reciprocity facilitates breastfeeding in term and Kangaroo Care in preterm infant	Implicit use of NNBO	Coherent conceptual integration between mother-infant reciprocity and behavioural state organization
Nursing (Barnard 1973, Barnard <i>et al.</i> 1984, Sumner <i>et al.</i> 1999)	Reinforced current knowledge base that premature infants have immature NBO. By manipulating the environment, the term and preterm infant is better able to regulate states, which then improves contingency patterns of communication between mother and infant/child	'Keys to Caregiving' is an educational intervention to improve behavioural state regulation and mother-infant interaction. Content consists of feeding interaction, state modulation, and infant state, behaviour and cues	Consistency in meaning and use that is maintained in varied contexts	Coherent conceptual integration between the mother-infant contingency and NNBO. The concept holds its boundaries in the term and preterm neonatal periods
Paediatric medicine (Brazelton 1978, 1979, Brazelton & Nugent 1995)	Pivotal in recognizing NNBO as a holistic phenomenon, with the neonate as an active and competent participant in shaping his/her NNBO. Integrated and translated prior work on the infant's neurological integrity, competency in state regulation, and reciprocal interaction with social and environmental stimuli	Developed the Neonatal Behavioural Assessment Scale, which measures 7 clusters of neurobehaviour and is used world-wide in research: 1 Habituation 2 Orientation 3 Motor 4 Range of State 5 Regulation of State 6 Autonomic Stability 7 Reflexes	Popularized the term NNBO. Consistent in use and meaning of NNBO	Logical outcome of a holistic perspective on the neonate as an open evolving living system in dynamic reciprocal interaction with its internal and social environment
Psychology (Feldman <i>et al.</i> 1999, Feldman 2006, Feldman & Eidelman 2006)	Disrupted periods of sensitive development in the preterm can be supported through positive mother-infant interaction. Aspects of NNBO (state organization, cardiac vagal tone, orientation, and arousal) are predictive of mother-infant synchrony	Mother-infant synchrony is viewed as both an independent (modulator) and dependent outcome of NNBO	Consistent in meaning and use of NNBO	Coherent conceptual integration between the mother-infant synchrony and NNBO

Influential researchers and their disciplines	Epistemology	Pragmatic	Linguistic	Logistic
Nursing (Holditch-Davis & Thoman 1987, Holditch-Davis 1990, Holditch-Davis <i>et al.</i> 2003)	The preterm infant has attenuated NBO. Supporting sleep-wake cycles facilitates self-regulation and long-term development	Researched the detailed organization of sleep-wake cycles of preterm infants as a predictor of neurobehavioural outcomes and to identify at-risk infants for early intervention	Consistency in meaning and use of behavioural state as a variable of NBO	Coherent conceptual integration between the preterm infant's sleep-wake organization and NNBO
Psychology (Horowitz 2000, Horowitz <i>et al.</i> 1983, Horowitz <i>et al.</i> 1978)	Sensory experience sculpts NBO	Documented sophisticated capacities of the neonate	Consistent in meaning and use of NNBO	Intrinsic relationship between sensory experience and NNBO
Paediatric psychology (Lester 1983, Salisbury <i>et al.</i> 2005)	Emphasized the developmental concept of integrity through continuous change. Infants demonstrate individual adaptive capacities. NBO originates in the fetal period	Researched psychometrics of Brazelton's NBAS, NICU Network Neurobehavioural Scale, and pilot studies of Fetal Neurobehavioural Coding Scale	Consistent in use and meaning of neurobehaviour as the interface between brain and physiology	The concept holds its boundaries in the context of fetal, preterm and neonatal periods
Developmental psychology (McGraw 1939a, 1943, Dalton 1998)	Emphasized motor and reflex development. An early researcher to view infants as having interconnected behavioural patterns that emerge through bi-directional interaction between structure and function. Systems continually reorganize into new configurations of stability for the emergence of maturing systems	Limited in outcome measures. Pioneer of bi-directional relationship between brain and behaviour. Criticized for not including the environment	Complex neurological terms	Questioned assumptions of reflexivity and maturationalism
Nursing (Medoff-Cooper & Ray 1995, Medoff-Cooper 2005, Medoff-Cooper & Ratcliffe 2005)	Described the longitudinal development of sucking organization in the preterm and full-term infant as a reflection of NBO	Nutritive sucking organization (e.g. coordinated patterns of sucking pressure, number of sucks and bursts, suck duration, suck-burst ratio, and interburst width) is a valuable research outcome to measure NBO and predict developmental outcomes	Consistency in meaning and use of sucking organization as a variable of NBO	Intrinsic relationship between sucking organization and NNBO
Psychology (Fox & Porges 1985, Porges 1996, 2007)	Emphasizes the role of the primitive autonomic nervous system in self-regulation. Basic neurophysiological systems coordinate to culminate in self-regulation, which promotes social interaction	Polyvagal theory: cardiac vagal tone predicts developmental outcome	Implicit use of NNBO	Intrinsic relationship between autonomic regulation and NNBO
Medicine (Prechtl 1974, Einspieler & Prechtl 2005)	Neurological integrity is the physiological basis of NBO	Developed standardized neurological assessments. Used physiological outcome measures of respiration, eye movement, vocalization, and general movement	Consistent in meaning of the neurological dimension of NBO	Coherent conceptual integration between neurological integrity and NBO
Psychology (Sameroff 1975a,b, Sameroff & Mackenzie 2003)	Challenged the mechanistic view of human development. Introduced that development occurs within a continuous reciprocal interchange between the individual and environment	Applied his Transactional Model of Development as a continuous transaction between infant/child, caretaker, and environment	Consistency in meaning and use that is maintained in varied contexts	The concept holds its boundaries beyond the neonatal period
Developmental psychology (Thoman 1975, Thoman <i>et al.</i> 1987, Thoman & Whitney 1990)	Behavioural states reflect the competency of CNS, and are a window into NBO. States are an antecedent, mediator, modulator, and elicitor of environmental interaction	Originally described 11 states, that were later synthesized into 6 states, which are frequently used by researchers: State I: Quiet sleep State II: Active sleep State III: Drowsy State IV: Quiet alert	Consistency in meaning and use of behavioural state, but did not use the term NNBO	Clearly defined relationships between states and NBO

Influential researchers and their disciplines	Epistemology	Pragmatic	Linguistic	Logistic
Developmental psychology (Cohn & Tronick 1988, Tronick 1989)	Infants emotionally communicate within a reciprocal feedback system with the environment. They regulate their state in relation to internal goals (emotional and physiological homeostasis) and external goals (interaction with animate and inanimate environment)	State V: Active alert State VI: Fussy-Crying Detailing the infant's emotional communication informs clinical practice	Self-directed and other-directed regulatory behaviours	The concept holds its boundaries beyond the neonatal period
Nursing (White-Traut & Hutchens-Pate 1987, White-Traut <i>et al.</i> 2002a,b)	Early sensory experience modulates NBO. Preterm infants exhibit attenuated NBO, therefore early multisensory interventions strengthen the autonomic nervous system and facilitate the emergence of hierarchical neurobehavioural development	Translational application of NBO. Auditory Tactile Visual Vestibular intervention was developed to improve NBO in preterm and at-risk infants. Improved NBO enhances mother-infant interaction and feeding	Implicit use of NNBO	Coherent conceptual integration between the preterm infant's NBO and NNBO
Psychology (Wolff 1973, 1987, Wolff & Ferber 1979)	Identified distinguishable patterns of state behaviour in the neonatal period	State I: Regular sleep State II: Irregular sleep State III: Drowsy (later redefined as descriptive state transitions vs. discrete states) State IV: Alert inactivity State V: Waking activity State VI: Crying Used outcome measures of sucking patterns, visual habituation, auditory responses, and social interaction	Consistency in meaning and use of behavioural state, but has not used the term NNBO	Evolved in his appreciation of the infant's complexity. A leader in creating the boundaries of NBO

Note. NNBO, neonatal neurobehavioural organization; NBO, neurobehavioural organization.