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**Remembering the Pain of Childhood: Applying a Developmental
Perspective to the Study of Pain Memories**

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1. Introduction and Background

How pain leaves its lasting mark on the memories of individuals has long fascinated psychologists and philosophers [23,30]. The importance of memory for pain lies in its role in pain assessment [38], its powerful influence on subsequent pain experience [15,35], and its potential role in the development and maintenance of pain chronicity [13,48]. The notion of “erasing” memory traces of pain has been compelling to researchers and clinicians alike [44] and treatment of pain has been conceived of as extinction of pain memory [12].

This review will characterize various definitions of pain memories used in the literature, and describe changes in cognitive and social development that may influence children’s memories for pain. Based on this summary, a research agenda is presented to stimulate and advance research in this area. Among pediatric populations, there is a need for developmentally informed examinations of pain memory due to important developmental changes in memory and learning [3,11,42] and pain processing [10,9,51,52].

2. Defining “Pain Memories”

Broadly speaking, memory is the retention of information that influences subsequent responses at behavioral and/or neuronal levels [44]. The term “pain memories” was introduced by Katz and Melzack [24] to describe amputees’ explicit and vivid reports of “re-experiencing” pain in the amputated limbs that was similar to the pain felt in those limbs prior to injury. Memories can be either explicit (declarative) or implicit (non-declarative). Explicit memories are consciously retrieved, can be actively searched, and typically can be verbalized. They include

episodic (memory of a past experience) and semantic (factual, identity, classification) memories. By contrast, implicit memories do not require awareness when acquired and retrieved, and include procedural memory (e.g., skill learning), priming (e.g., changes in performance accuracy and/or speed that can be attributed to previous exposure), and non-associative (e.g., sensitization) and associative (e.g., conditioning) processes. Within the context of pain, sensitization and conditioning have been studied most extensively. Specifically, sensitization is considered to be a key process when pain becomes chronic [56]. The implicit memory system and its underlying neurobiology are apparent virtually from birth, whereas the explicit memory system undergoes considerable development throughout childhood [3]. Whether or not infants are truly capable of consciously recalling the past is widely debated and impossible to determine given their lack of verbal abilities; however evidence from behavior-based imitation tasks (e.g., imitating a previously learned event sequence with novel objects) suggests that explicit memories are present in the first year of life [43].

2.1. Development of Implicit versus Explicit Pain Memories

Mirroring definitions of pain memories often used in the adult literature [13,32,44,48], pain memories would include forms of implicit learning (e.g., sensitization, conditioning) and alterations in ascending and descending pain pathways that influence the magnitude and threshold of pain response [e.g., 49,51,55,21]. For example, researchers demonstrated that neonatal intensive care and surgery among children born extremely preterm was related to alterations in somatosensory perception over a decade later [51]. Researchers have questioned whether there is a critical period (i.e., defined period whereby nociceptive input and implicit learning are most likely to cause long-lasting alterations in pain and sensory responding) during which these "pain memories" exert the greatest impact over time. Growing evidence suggests

that such sensitive time windows may exist in infancy [4,10,45,21,51,52,28]. Although both implicit and explicit memories can influence later responses to a nociceptive event, it has been argued that implicit memories, by virtue of not requiring one's awareness, are more influential to subsequent pain and more difficult to eradicate [13].

2.2. Applying a Developmental Perspective to Pain Memories

The terms “pain memories” and “memory for pain” have been used to describe a variety of diverse processes with different underlying learning mechanisms across the lifespan. For example, pain memories include sensitization following painful surgical procedures in newborns [49] and sensitized withdrawal reflexes associated with persistent pain in infants [1], classically conditioned behavioral responses among infants following heel sticks [50], recalled experimental and clinical pain using rating scales [36,41,15,27], recalled contextual details from painful medical procedures [6,7], or semantic memory among older adults with dementia [37]. Given the heterogeneity among these diverse processes all referred to as “pain memories”, we propose that developmentally sensitive investigations of pain memories require understanding of how cognitive and social development influences the development and expression of memory systems early in life.

3. Hallmarks of Cognitive and Social Development during Childhood and How They [may] Relate to Pain Memories

Models of explicit memory describe the development of key cognitive and social processes during infancy and childhood [34]. The nervous system changes and grows and alterations occur in structure and function that are brought about by development. In particular, key changes in explicit memory systems occur throughout childhood. Below we review some of

the key areas of cognitive and social development that may influence pain and pain memory development (see also Figure 1).

3.1. The Cognitive Self and Emergence of Language

During the first 3 to 4 years of life, children's cognitive skills, including their mnemonic abilities, undergo rapid changes at physiological and psychological levels [2]. During this time, implicit memory is supplemented by the emergence of explicit autobiographical and semantic memories. Major developmental milestones in early childhood include the development of language and the emergence of the "cognitive self", which influence autobiographical memory development [22]. The cognitive self, a knowledge structure that organizes and roots memories to one's self, is considered a necessary precursor for autobiographical memories [22]. Language enables the child to share their past with others and although not a necessary precursor for the formation of these memories, it has been shown to impact their retention [33]. How early pain experiences and memories influence and are influenced by pain language, which emerges as early as 18 months of age [46], is unknown.

3.2. The Dynamic Social Environment

3.2.I. Evolving Parent-Child Relationship

Through language-based interactions, caregivers are highly influential in the development of children's autobiographical memories [2,39] and pain language [8]. Caregivers may also play a role in bringing implicit pain memories into children's conscious awareness and altering their representation. This may occur through caregivers' integration of early pain experiences into family narratives, invariably influencing children's emerging autobiographical pain memories by either overwriting an existing memory or becoming adopted by the child as their own. Indeed,

young children's event memory systems are undifferentiated to source such that another individual's linguistic account of an event is not differentiated from the child's direct experience, and the former often takes precedence because it occurs later in time [33]. It is important to consider caregivers' own memories of child pain given their potential role in influencing language-based interactions about pain, health care interactions that caregivers largely control at this stage (e.g., immunizations), and child cognitions and expectancies about pain.

3.2.II. Adolescent Social Development

During the period of adolescence, there is significant maturation of the frontal lobe, amygdala, hippocampus, HPA axis, and brain circuits underlying affective and behavioral regulation. These changes influence the emotional processing of events, decision making, goal directed behavior, learning, and memory [31]. Normative adolescent development is also marked by identity formation, individuation, and autonomy from caregivers [26]. While vicarious (modeling) and operant learning and verbal interactions with caregivers are important for pain memory development during earlier developmental stages, the peer group becomes increasingly important in adolescence, influencing the way that youth communicate about and express pain [18]. Undoubtedly, the conversational exchanges adolescents have about pain as well as peer-modeling of pain behaviors influence the reframing and evolving quality of pain memories.

The influence of early pain experiences may be more readily examined in adolescence. Most types of pediatric chronic pain emerge during adolescence, with higher rates emerging in girls around the time of pubertal development [25], and investigations have linked early pain experiences to subsequent pain responses in adolescence [21]. Given that memory has been

implicated in worsening trajectories of pediatric pain [35], understanding such potential biological and social influences on explicit memories is important [20].

3.3. Increasing Knowledge Base: Growth of Semantic Memory

As general factual knowledge expands in the later stages of childhood and adolescence, semantic memory for pain would be expected to show corresponding development. [54]. The understanding of what pain is and how ones cognitive and affective processes modulate pain grows over the course of cognitive development. Whereas young children relate the experience of pain almost exclusively to external cues or the situational context, older children and adolescents have a basic understanding of the physiological nature of pain and its susceptibility to the influence of affective states and thoughts [14,19]. Concomitantly, with increasing age, children rely more on cognitive coping strategies, which, in turn, can be adaptive (e.g., distraction, positive self-statements) or maladaptive (e.g. catastrophizing [53]). Although unexamined, this cognitive development and change in coping behavior may also in part account for differences between adolescents and children in their responses to the same painful event [16,17], aside from changes in pain sensitivity [5].

4. Agenda for Future Research

Empirical examinations of children's memories for pain are relatively recent. There remain important knowledge gaps that will require methodological advances and application of a developmental perspective of pain memories to propel forward this growing area of inquiry. We propose the following research agenda focusing on methodology and specific developmental processes relevant to pain memories in childhood.

4.1. Relationship between Implicit and Explicit Memories Acquired during Development

Whereas implicit learning and memory emerge very early in life, explicit learning and memory develop later and are closely tied to cognitive development. Thus far, surprisingly little is known about the mutual influences of implicit and explicit memory formation and retrieval, although both types of pain memories are thought to play important yet different roles in the experience of acute and chronic pain [12]. Unlike infancy, the role of implicit memories for pain formed at later stages of childhood and adolescence has been largely overlooked [47,40]. Beyond examination of differences in pain responding as a result of previous painful experiences, implicit memories can be assessed using measures of priming (e.g., word-stem/fragment completion, degraded picture identification; [29]). Nevertheless, few tools currently exist that directly assess implicit memory for an experience of pain itself.

To provide a more comprehensive assessment of pain memories, researchers are encouraged to employ qualitative assessment. This may inform measure development and enable categorization of the richness of explicit pain memories not permitted using single-item response scales. Specifically, assessment of free recall should occur first to permit examination of children's spontaneous recall unbiased by probed questions and imposed language. Then, assessment of specific details of the past experience using probed/cued recall should be conducted. We recommend assessment of the multidimensional nature of past pain to include the sensory, affective and contextual aspects of the experience. Longitudinal assessment of pain memories at multiple points in time, including during and several points following painful experiences is needed.

4.2. The Role of Pain Language in Pain Memory Development

The emergence of language in later infancy and into the toddler years is a critical cognitive achievement that directly impacts both the expression and retention of one's past [33]. Language also permits the child to recall and reconstruct their past with others, and such interactions have considerable influence on evolving autobiographical memories [39]. Future research should extend research on the development of pain language in toddlers [8,46] to examine its role in the development of children's early memories for pain. It is likely that both play a role in pain coping and expression as children develop.

4.3. Social Context and Pain Memories

Largely excluded from examinations of children's memories for pain, but not other areas of memory research, are caregivers. We argue that this exclusion is developmentally inappropriate. Examination of the influence of caregivers' own pain memories and expectancies is needed. Before the emergence of language, caregivers' memories of child pain experiences during infancy may play an important role in the pain language and narratives that children are exposed to, thereby influencing the development of their explicit memories of pain. Caregivers may also play a pivotal role in the interaction of early implicit and later explicit memories for pain. As adolescents develop more autonomy and reliance on caregivers shift more towards the peer group, examination of peer behaviors and relationships in the development and reframing of pain memories is warranted.

Appreciation of memory development in childhood and the unique contextual factors affecting memory expression at each stage will shed light on the cognitive underpinnings of pain trajectories across the lifespan.

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Figure Caption

Figure 1. Cognitive and social developmental factors underlying the formation and expression of pain memories in childhood.

Figure depicting key memory constructs that emerge and interface over time with various aspects of cognitive and social development. We suggest that these social and cognitive influences on pain memory development and expression are dynamic and interact over time. These factors and processes are placed at points in time where we hypothesize their influence on pain memories to be particularly important and worthy of empirical investigation; however, these factors and processes may also exert influence on pain memories at other times in development.