The dynamics of pain avoidance: The exploration-exploitation dilemma

Angelos-Miltiadis Krypotos[1,2], Geert Crombez[3], & Johan W.S. Vlaeyen[1,4]

[1] Research group of Healthy Psychology, KU Leuven

[2] Department of Clinical Psychology, Utrecht University

[3] Department of Experimental-Clinical and Health Psychology, Ghent University

[4] Department of Experimental Health Psychology, Maastricht University

Paper accepted in PAIN®

Author note

Correspondence concerning this article should be addressed to Angelos-Miltiadis Krypotos, Tiensestraat 102, 3000 Leuven, Belgium. E-mail: amkrypotos@gmail.com. URL: https://www.uu.nl/staff/AMKrypotos

The dynamics of pain avoidance: The exploration-exploitation dilemma

Pain can be described as an urge to escape from bodily threat, and is a driver of avoidance learning [8,13,66,69]. Although avoidance can be helpful in the early phases of pain, it can interfere with individuals' valued life goals, causing disability and distress [15,32,64]. Specifically, when performed after an injury has healed, avoidance may prevent individuals from updating their knowledge about their body, resulting in the maintenance of avoidance even when pain is no longer present (e.g., [37,49]). The idea that avoidance is a maintaining factor in disabling pain has inspired research about how avoidance is learned and can be reduced [8,37,66]. Despite this increased interest, current pain avoidance research has yet to fully acknowledge at least two observations in clinical practice. The first observation relates to avoidance reduction techniques (exposure-based therapies) and their laboratory parallels (e.g., extinction with response prevention procedures). Across those techniques there is often the assumption that performing the avoidance response is unnecessary when the injury has healed (often the case in chronic pain) and thus avoidance should be stopped. However, a feared movement will often remain painful, possibly urging individuals to continue avoiding such actions [8]. Second, pain avoidance is commonly conceptualized and tested as the result of simple learning processes, where individuals quickly learn to avoid performing movements paired with pain or harm [28]. However, in everyday life pain avoidance emerges in dynamic environments, where individuals sometimes will not perform an action that is expected to increase pain or bodily harm, but at other times they will [28]. These observations suggest that current avoidance research need to consider pain avoidance as a *dynamic* phenomenon, meaning that the benefits and the costs of avoidance may vary as a function of the goals and the contexts within it is expressed. In this topical review we argue that reconceptualizing the dynamic nature of pain avoidance in terms of how individuals solve the so-called *exploration-exploitation* dilemma (EED) opens a new window on how to study and treat avoidance in chronic pain [27]. Specifically, we argue below that a EED framework offers a more informative approach for investigating laboratory avoidance compared to existing procedures (e.g., conditioning).

Acquisition and maintenance of pain avoidance

Traditionally, avoidance has been argued to be the outcome of learning that situations are predictive of aversive events (e.g., pain) and as such the appropriate response should be emitted to prevent such events to occur [37,66,68]. Going beyond this traditional view, motivational accounts consider avoidance as the result of a trade-off between preventing pain with some cost, versus achieving a valued goal despite pain (e.g., [4,7]). There are several ways to understand this trade-off. Here we describe it in terms of the organism balancing between *exploration and exploitation*. Exploration is the search for novel information whereas exploitation is utilizing the knowledge already achieved (see [36] for alternative definitions). Exploration is typically associated with curiosity [40] whereas exploitation has been associated with dedicated, purposeful, goal-directed actions over an extended period [19]. Learning usually starts with exploration, which then gradually converges to the exploitation of the knowledge that is associated with better outcomes [19]. Both exploration and exploitation are imperative for survival [14,22]. Explorative behavior enables the discovery of actions that lead to stronger rewards, and exploitation is the repetition of choices known to be favourable. However, both hold risks. Exploration may increase the risk of wasting unnecessary energy or the occurrence of unknown threats [5], whereas exploitation may hold the risk that actions are repeated despite diminishing benefits [5,36,56]. How individuals balance their decisions between exploration and exploitation is a key topic of research in computer science [56], machine learning [2], and neuroscience [53]. Pain avoidance research may greatly benefit from that research, especially those from the computer sciences [48,57].

The theoretical models of EED [17,36,57] (see Figure 1 for an example) describe how individuals learn to predict future salient events (either appetitive or aversive) by making a cascade of decisions that may lead to aversive or appetitive outcomes [53]. In each step (or state [57]), the individual makes predictions about the outcomes of each action. The predictions are based on multiple sources of information, broadly classified as a) individual (e.g., personal knowledge about a situation, stress levels [31], b) environmental (e.g., the available resources in each situation), and c) social (e.g., knowledge acquired through others; refer to [20,24] for relevant research).

------ Insert Figure 1 here ------

The integration of all this information results in so-called *prior knowledge* in Bayesian models, or *generative model* in active inference models (see also [55,60]), about the actions/stimuli and their probability of being followed by aversive/appetitive outcomes. Using that prior knowledge [58,59], individuals have the option to explore alternative ways to search for new or additional knowledge (exploration) or decide to take advantage of the information they already have (exploitation). After deciding and having performed the chosen action, the outcome of the behaviour is observed, and the knowledge of the individual is updated accordingly. In case of expectancy confirmation, the prior knowledge is strengthened whereas in the opposite case the prior knowledge is weakened. The larger the discrepancy between the prediction and the actual event, the more learning occurs [38,50].

In comparison to the current learning models for studying avoidance in pain [26], these EED models can provide a better account of avoidance for at least three reasons. First, EED models can account for the dynamic nature of every-day behaviour, where avoidance may be expressed in some contexts (e.g., when pain levels or risk of bodily harm are high) but stopped in other situations (e.g., when pain levels remain but are low), depending on the current circumstances [30,61]. This dynamic character of avoidance aligns well with the dynamic nature of pain. For example, using Experienced Sampling Methods (ESM), where participants report pain levels multiple times a day, Selby et al., [52] showed that pain fluctuates over time in individuals committing self-injury. ESM could also be expanded to track avoidance as well (see also [9] for another ESM study with pain). Second, by focusing on variability in past experiences, EED can account for individual differences in excessive avoidance acquisition and reduction during exposure treatments, with earlier negative experiences [23] resulting in faster acquisition and slower extinction of avoidance behavior [35,62]. To illustrate, evidence suggests that exploration increases with more physical strength, cognitive capacity, and reduced levels of dopamine (see [4] for a review). It remains to be tested whether these individual differences also play a role in pain avoidance. A third reason is that research in the animal literature has extensively delved into EED, highlighting the continuity between human and non-human animals. Research on non-human animals has inspired human studies, offering fresh perspectives and challenges in grasping complex human behavior (see [1,36,41] for the relevant literature). This involves human research on associative learning theory, which heavily leans on animal studies[11], like those examining the role of conditioning in pain[66]. Additionally, studies have explored decision-making amid varying levels of uncertainty, aiming to compare human and non-human decision-making strategies, particularly in economic decision-making scenarios[10].

Collectively, EED models can help in accounting for dynamic, real-life environments, holding promise that we can have a more accurate account of behavioural decision making in pain. In the next section, we expand on how EED models can help in reconsidering and expanding current views of the extinction of avoidance behavior in individuals with chronic pain.

Extinction of pain avoidance

One of the challenges in clinical practice is the reduction of disabling avoidance. Exposure-based treatments are becoming more prevalent and have demonstrated efficacy in reducing levels of pain-related fear [18,51,65]. The aim of exposure is to create a discrepancy between the prediction that certain pain-relevant (proprioceptive or interoceptive) stimuli lead to increased pain or bodily harm and the actual event (e.g., that harm does not necessarily follow). For example, if a patient is afraid of bending because of an expected spine injury, they will be encouraged to bend, creating the surprising experience that this movement does not result in actual injury. These expectancy violations provide opportunities for new learning (e.g., bending is safe) and are also in line with the theoretical models described in the previous section. Despite the ample evidence that exposure-based treatments successfully reduce pain-related fear, recurrence of fear and avoidance is common [8,54]. Here, we suggest that exposure-based treatments can be seen as a way to optimize the balance between exploration and exploitation [67].

First, drawing from the theoretical framework explained above (see Figure 1), increasing curiosity between the actions that are expected to result in pain and their actual outcomes will encourage exploration [16,40]. This can be done by increasing the uncertainty that pain will follow a pain-related stimulus or action. By this strategy, the information value of the pain-related stimulus or action increases, and thus exploration is encouraged [40]. Second, encouraging individuals to engage in novel actions that are valuable on their own is likely to promote exploration (see [1] for relevant animal research). In addition, rewards for novel actions can be added, or reminding individuals that some feared actions can be followed by a rewarding outcome. Third, from the EED perspective, exposure can be considered a dynamic strategy that varies in time and context. Depending on the goal, the individual switches between exploring new actions and exploiting known ones. At the start of the treatment, new knowledge is acquired about the meaning of pain, and the associations between injury, pain, avoidance, and the disabling interference in daily life activities. After the exploration of this new knowledge, there could be a gradual shift in frequency from less exploration and more exploitation. In that sense, a key goal of exposure treatment is finding a balance between rest vs. activity, stability vs. change, and inflexibility vs. flexibility through a sequence of behavioral experiments. The presented EED model could prove helpful also for interpreting other therapies than exposure. For example, pacing [44] or the regulation of boom-bust pattern of activities [43] can also be reconsidered as a strategy to shift between activity and rest, or how it is here explained exploration of novel actions or exploitation of known ones.

The EED also holds the potential to introduce a novel mechanistic framework for comprehending behavioural responses to pain, which can contribute to the development of treatments at an individual level. The progression of computational modelling (e.g., [29]) and machine learning presents modern algorithms that can enhance our understanding of the mechanisms underlying pain-related behavior. The combination of formal models and clinical knowledge could also help to better understand and reduce excessive pain avoidance. This is the case with computational medicine, where computational models are used to capture all information known about a enabling the derivation of predictions regarding potential therapeutic targets[6]. Also, this computational approach is already successful in areas like clinical psychology[3]. For instance, by identifying variations in reward reinforcement patterns on an individual basis, this knowledge can be translated into treatment paradigms that require enhanced reward stimuli compared to standard one-size-fits-all treatment protocols. It is timely for pain researchers to embrace the advancements in computational research and effectively translate those insights into the domain of pain.

Avenues for future research

The application of the EED in the field of pain offers new opportunities for the study of pain avoidance, and below we present some research lines.

First, research has revealed various individual factors that can influence EED choices (see [36] for a review), but these await corroboration in the field of pain. Furthermore, it would be beneficial to examine individual difference variables that have been identified as relevant in the context of fear learning (e.g., intolerance of uncertainty [27,42]), avoidance learning (e.g., emotional stability [33]), or context (e.g., where fear extinction takes place [46]). This knowledge could help in detecting which individual characteristics predict imbalances between exploration and exploitation behaviour. Identifying individual differences that forecast a tendency toward increased exploitation could aid in tailoring personalized care for individuals with chronic pain. In this line of work, single case experimental designs [25,45] are particularly useful as they allow testing different treatments using idiographic measures without requiring large samples.

Second, certain clinical insights have not yet been incorporated into theoretical frameworks and experimental research. To illustrate, exposure-based protocols typically account for the dynamic nature of pain, and formulate personalized protocols tailored to individual clients. This is currently not the case with formal theories of pain. Computational modelling enables the connection of theoretical models of psychological responses (e.g., pain avoidance) to experimental observations [29]. For example, interoceptive psychopathology and pain have been explained via active inference models [47]. However, such models are often only informed by laboratory data and not so much of clinical data. The combination of formal models and clinical knowledge could also help to better understand and reduce excessive pain avoidance [63].

Third, decision-making implies that an explicit decision is made. Making no decision at all could also be construed as avoidance behavior [12,21,34,39], such as is the case when postponing a serious surgical operation unless more information is acquired about the current condition of the patient. Such non-decisions seem to be just another instance of the EED, where individuals prefer sticking with the information they have, rather than risking experiencing pain by exploring new options.

Lastly, a major challenge is how to model the complexity of real-world situations, where there is a panoply of options to choose from. In experimental studies so far, participants usually perform highly controlled tasks including few options and relatively simple probability distributions over pain and rewards following each option [27]. There is a need for studying EED in real world environments using wearable sensors capturing moment-to moment fluctuations [61], for example by using geolocation tracking to quantify exploration variability in daily movement patterns. To illustrate, Saragosa-Harris et al. [34] found that days of higher exploration were associated with greater positive affect and greater social connectivity, irrespective of age. Higher mean exploration was also associated with higher risk taking among adolescents [34]. These methods are promising, as they could be used to track the effects of exposure treatments on the exploration-exploitation balance in naturalistic settings of the patient.

Conclusion

In this review we propose to study pain avoidance from the lens of the EED. To move beyond the idea that avoidance is something that once learned in acute pain and always will be performed in chronic pain, we suggest viewing behaviour as a chain of exploration-exploitation decisions irrespective of pain duration. The EED framework is a value-free new approach of pain avoidance considering its dynamic nature in real life environments. Such view holds the promise for designing more refined individually tailored pain treatments.

Acknowledgements

The present work was supported by an FWO grant (Reg. # G071118N) awarded to Johan W.S. Vlaeyen and Geert Crombez, as well as an FWO grant (Reg. # 12X5320N) and an NWO grant (Reg. # 401.18.056) to Angelos-Miltiadis Krypotos. Johan W.S. Vlaeyen is also supported by the 'Asthenes' long-term structural funding–Methusalem grant by the Flemish Government, Belgium (METH/15/, the NWO gravitation program "New Science of Mental Disorders": www.nsmd.eu (Reg, # 024.004.016) by the Dutch Research Council and the Dutch Ministry of Education, Culture and Science, and the National Institute for Health and Disability Insurance, Belgium (NIHDI: #2018-00047).

Conflict of interest

None.

References

[1] Archer J, Birke LIA. Exploration in Animals and Humans. Van Nostrand Reinhold (UK), 1983.

[2] Auer P. Using confidence bounds for exploitation-exploration trade-offs. J Mach Learn Res 2003;3:397–422.

[3] Aylward J, Valton V, Ahn W-Y, Bond RL, Dayan P, Roiser JP, Robinson OJ. Altered learning under uncertainty in unmedicated mood and anxiety disorders. Nat Hum Behav 2019;3:1116–1123.

[4] Claes N, Crombez G, Vlaeyen JWS. Pain-avoidance versus reward-seeking: an experimental investigation. Pain 2015;156:1449–1457.

[5] Cohen JD, McClure SM, Yu AJ. Should I stay or should I go? How the human brain manages the trade-off between exploitation and exploration. Phil Trans R Soc B 2007;362:933–942.

[6] Computational Medicine: Translating Models to Clinical Care | Science Translational Medicine. n.d. Available: https://www.science.org/doi/full/10.1126/scitranslmed.3003528?casa_token=C-mCz2Z3a-oAAAAA:dn2Tyb6ixyi3zJ7TVY1Iz7-zq9RfqPNW3v6oHO_ZWxI0nv0v4bl0WZg7_qONlfTwfzKpqYL8f9APVbQ. Accessed 26 Jan 2024.

[7] Crombez G, Eccleston C, Van Damme S, Vlaeyen JWS, Karoly P. Fear-avoidance model of chronic pain: the next generation. Clin J Pain 2012;28:475–483.

[8] Crombez G, Eccleston C, Vlaeyen JWS, Vansteenwegen D, Lysens R, Eelen P. Exposure to physical movement in low back pain patients: Restricted effects of generalization. Health Psychology 2002;21:573–578.

[9] Crombez G, Viane I, Eccleston C, Devulder J, Goubert L. Attention to pain and fear of pain in patients with chronic pain. J Behav Med 2013;36:371–378.

[10] De Petrillo F, Rosati AG. Variation in primate decision-making under uncertainty and the roots of human economic behaviour. Phil Trans R Soc B 2021;376:20190671.

[11] Delgado MR, Olsson A, Phelps EA. Extending animal models of fear conditioning to humans. Biological Psychology 2006;73:39–48.

[12] Dhar R. The Effect of Decision Strategy on Deciding to Defer Choice. Journal of Behavioral Decision Making 1996;9:265–281.

[13] Eccleston C, Crombez G. Pain demands attention: A cognitive–affective model of the interruptive function of pain. Psychological Bulletin 1999;125:356–366.

[14] Eliassen S, Jørgensen C, Mangel M, Giske J. Exploration or exploitation: life expectancy changes the value of learning in foraging strategies. Oikos 2007;116:513–523.

[15] Fallon N, Brown C, Twiddy H, Brian E, Frank B, Nurmikko T, Stancak A. Adverse effects of COVID-19-related lockdown on pain, physical activity and psychological well-being in people with chronic pain. British Journal of Pain 2021;15:357–368.

[16] Friston KJ, Lin M, Frith CD, Pezzulo G, Hobson JA, Ondobaka S. Active Inference, Curiosity and Insight. Neural Computation 2017;29:2633–2683.

[17] Ghavamzadeh M, Mannor S, Pineau J, Tamar A. Bayesian Reinforcement Learning: A Survey. FNT in Machine Learning 2015;8:359–483.

[18] Glombiewski JA, Holzapfel S, Riecke J, Vlaeyen JWS, de Jong J, Lemmer G, Rief W. Exposure and CBT for chronic back pain: An RCT on differential efficacy and optimal length of treatment. Journal of Consulting and Clinical Psychology 2018;86:533–545.

[19] Gopnik A. Childhood as a solution to explore–exploit tensions. Philosophical Transactions of the Royal Society B: Biological Sciences 2020;375:20190502.

[20] Goubert L, Vlaeyen JWS, Crombez G, Craig KD. Learning about pain from others: an observational learning account. J Pain 2011;12:167–174.

[21] Han Q, Quadflieg S, Ludwig CJH. Decision avoidance and post-decision regret: A systematic review and meta-analysis. PLOS ONE 2023;18:e0292857.

[22] Hills TT, Todd PM, Lazer D, Redish AD, Couzin ID. Exploration versus exploitation in space, mind, and society. Trends in Cognitive Sciences 2015;19:46–54.

[23] Humphreys KL, Lee SS, Telzer EH, Gabard-Durnam LJ, Goff B, Flannery J, Tottenham N. Exploration—exploitation strategy is dependent on early experience. Developmental Psychobiology 2015;57:313–321.

[24] Karos K, Williams AC de C, Meulders A, Vlaeyen JWS. Pain as a threat to the social self: a motivational account. Pain 2018;159:1690–1695.

[25] Kazdin AE. Single-case experimental designs. Evaluating interventions in research and clinical practice. Behaviour Research and Therapy 2019;117:3–17.

[26] Krypotos A-M. Avoidance learning: a review of theoretical models and recent developments. Front Behav Neurosci 2015;9. doi:10.3389/fnbeh.2015.00189.

[27] Krypotos A-M, Alves M, Crombez G, Vlaeyen JWS. The role of intolerance of uncertainty when solving the exploration-exploitation dilemma. International Journal of Psychophysiology 2022;181:33–39.

[28] Krypotos A-M, Crombez G, Alves M, Claes N, Vlaeyen JWS. The exploration-exploitation dilemma in pain: an experimental investigation. Pain 2022;163:e215–e233.

[29] Krypotos A-M, Crombez G, Meulders A, Claes N, Vlaeyen JWS. Decomposing conditioned avoidance performance with computational models. Behav Res Ther 2020;133:103712.

[30] Krypotos A-M, Moscarello JM, Sears RM, LeDoux JE, Galatzer-Levy I. A principled method to identify individual differences and behavioral shifts in signaled active avoidance. Learn Mem 2018;25:564–568.

[31] Lenow JK, Constantino SM, Daw ND, Phelps EA. Chronic and Acute Stress Promote Overexploitation in Serial Decision Making. J Neurosci 2017;37:5681–5689.

[32] Lerman SF, Rudich Z, Brill S, Shalev H, Shahar G. Longitudinal Associations Between Depression, Anxiety, Pain, and Pain-Related Disability in Chronic Pain Patients. Psychosomatic Medicine 2015;77:333.

[33] Lommen MJJ, Engelhard IM, van den Hout MA. Neuroticism and avoidance of ambiguous stimuli: Better safe than sorry? Personality and Individual Differences 2010;49:1001–1006.

[34] Luce MF. Choosing to avoid: Coping with negatively emotion-laden consumer decisions. Journal of Consumer Research 1998;24:409–433.

[35] Meacham F, T. Bergstrom C. Adaptive behavior can produce maladaptive anxiety due to individual differences in experience. Evolution, Medicine, and Public Health 2016;2016:270–285.

[36] Mehlhorn K, Newell BR, Todd PM, Lee MD, Morgan K, Braithwaite VA, Hausmann D, Fiedler K, Gonzalez C. Unpacking the exploration–exploitation tradeoff: A synthesis of human and animal literatures. Decision 2015;2:191–215.

[37] Meulders A. From fear of movement-related pain and avoidance to chronic pain disability: a state-of-the-art review. Current Opinion in Behavioral Sciences 2019;26:130–136.

[38] Miller RR, Barnet RC, Grahame NJ. Assessment of the Rescorla-Wagner model. Psychological Bulletin 1995;117:363–386.

[39] Minor J, Miller L, Ditrichs R. The effect of an undecided alternative on resolution of approach-approach and avoidance-avoidance conflict situations. Psychon Sci 1968;12:375–375.

[40] Modirshanechi A, Kondrakiewicz K, Gerstner W, Haesler S. Curiosity-driven exploration: foundations in neuroscience and computational modeling. Trends in Neurosciences 2023;46:1054–1066.

[41] Mogil JS. Animal models of pain: progress and challenges. Nat Rev Neurosci 2009;10:283–294.

[42] Morriss J, Christakou A, van Reekum CM. Nothing is safe: Intolerance of uncertainty is associated with compromised fear extinction learning. Biol Psychol 2016;121:187–193.

[43] Murphy SL, Kratz AL. Activity pacing in daily life: A within-day analysis. PAIN® 2014;155:2630–2637.

[44] Nielson WR, Jensen MP, Karsdorp PA, Vlaeyen JWS. Activity Pacing in Chronic Pain: Concepts, Evidence, and Future Directions. The Clinical Journal of Pain 2013;29:461–468.

[45] Onghena P, Edgington ES. Customization of pain treatments: single-case design and analysis. Clin J Pain 2005;21:56–68; discussion 69-72.

[46] Papalini S, Ashoori M, Zaman J, Beckers T, Vervliet B. The role of context in persistent avoidance and the predictive value of relief. Behaviour Research and Therapy 2021;138:103816.

[47] Paulus MP, Feinstein JS, Khalsa SS. An Active Inference Approach to Interoceptive Psychopathology. Annu Rev Clin Psychol 2019;15:97–122.

[48] Pezzulo G, Parr T, Cisek, Paul, Clark A, Friston K. Generating meaning: active inference and the scope and limits of passive AI. Trends in Cognitive Sciences in press.

[49] Philips HC. Avoidance behaviour and its role in sustaining chronic pain. Behav Res Ther 1987;25:273–279.

[50] Rescorla R, Wagner A. A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and nonreinforcement. Classical Conditioning II: Current Research and Theory.1972, Vol. Vol. 2.

[51] Schemer L, Schroeder A, Ørnbøl E, Glombiewski JA. Exposure and cognitive-behavioural therapy for chronic back pain: An RCT on treatment processes. Eur J Pain 2019;23:526–538.

[52] Selby EA, Kranzler A, Lindqvist J, Fehling KB, Brillante J, Yuan F, Gao X, Miller AL. The Dynamics of Pain During Nonsuicidal Self-Injury. Clinical Psychological Science 2019;7:302–320.

[53] Seymour B, Daw ND, Roiser JP, Dayan P, Dolan R. Serotonin Selectively Modulates Reward Value in Human Decision-Making. J Neurosci 2012;32:5833–5842.

[54] da Silva T, Mills K, Brown BT, Pocovi N, de Campos T, Maher C, Hancock MJ. Recurrence of low back pain is common: a prospective inception cohort study. Journal of Physiotherapy 2019;65:159–165.

[55] Spelke ES, Kinzler KD. Core knowledge. Developmental Science 2007;10:89–96.

[56] Sutton RS, Barto AG. Reinforcement learning: an introduction. Cambridge, Mass: MIT Press, 1998.

[57] Sutton RS, Barto AG. Reinforcement Learning, second edition: An Introduction. MIT Press, 2018.

[58] Tabor A, Thacker MA, Moseley GL, Körding KP. Pain: A Statistical Account. PLoS Comput Biol 2017;13:e1005142.

[59] Tenenbaum JB, Griffiths TL, Kemp C. Theory-based Bayesian models of inductive learning and reasoning. Trends in Cognitive Sciences 2006;10:309–318.

[60] Toates F. Exploration as a motivational system - a Cognitive-incentive model. In: Archer J, Birke L, editors. Wokingham: Van Nostrand Reinhold (UK), 1983. Available: http://oro.open.ac.uk/66671/. Accessed 12 Oct 2022.

[61] Tottenham N, Shapiro M, Flannery J, Caldera C, Sullivan RM. Parental presence switches avoidance to attraction learning in children. Nat Hum Behav 2019;3:1070–1077.

[62] Trimmer PC, Higginson AD, Fawcett TW, McNamara JM, Houston AI. Adaptive learning can result in a failure to profit from good conditions: implications for understanding depression. Evol Med Public Health 2015;2015:123–135.

[63] Van Damme S, Moore DJ. From the clinic to the lab (and back)—a call for laboratory research to optimize cognitive behavioural treatment of pain. Transl Behav Med 2012;2:102–105.

[64] Vandael K, Vervliet B, Peters M, Meulders A. Excessive generalization of pain-related avoidance behavior: mechanisms, targets for intervention, and future directions. PAIN 2023;164:2405.

[65] Vlaeyen J, Morley S, Linton S, Boersma K, Jong J. Pain-Related Fear: Exposure-Based Treatment for Chronic Pain. 2012.

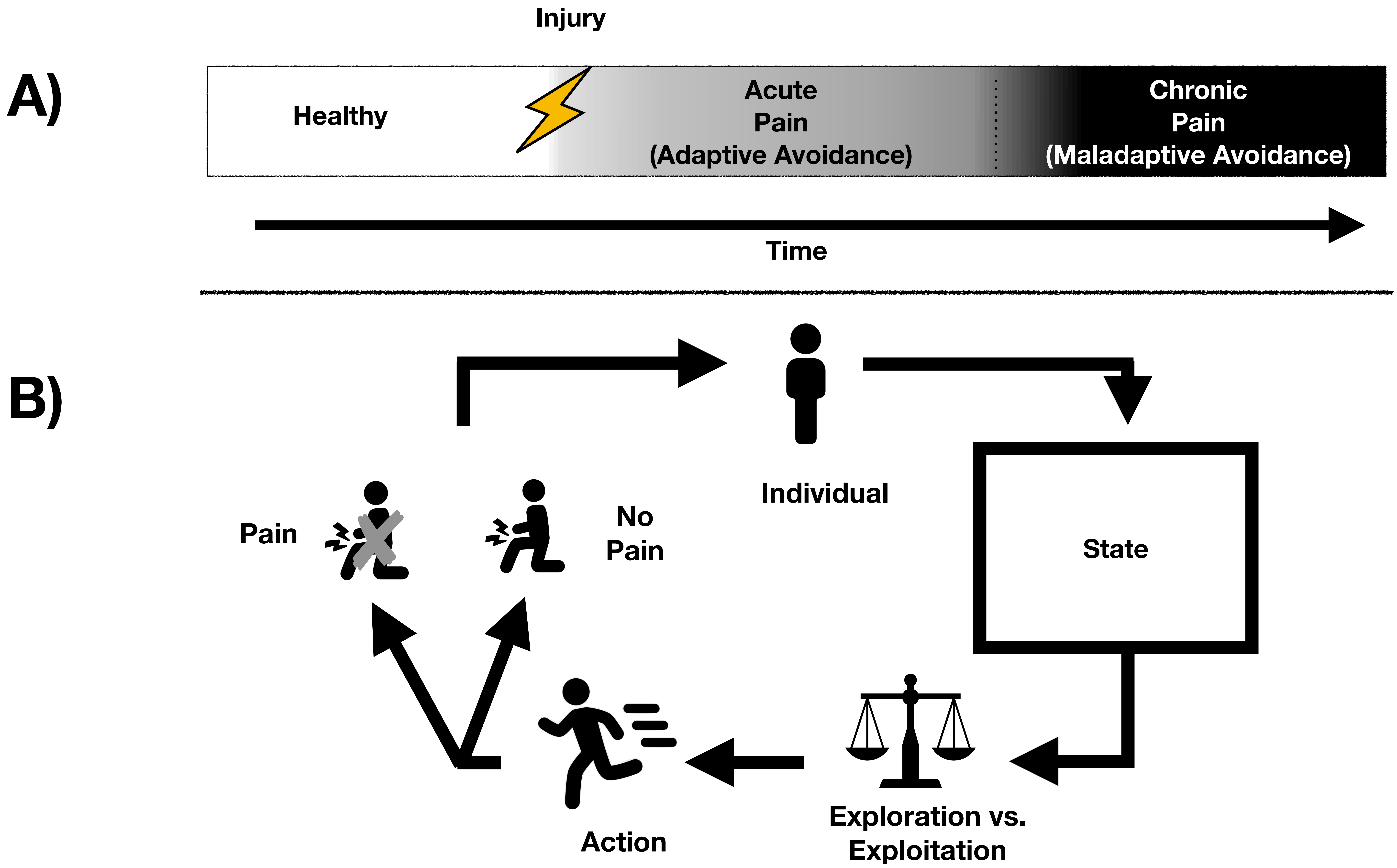
[66] Vlaeyen JWS. Learning to predict and control harmful events: chronic pain and conditioning. Pain 2015;156:S86–S93.

[67] Vlaeyen JWS, Crombez G. Behavioral Conceptualization and Treatment of Chronic Pain. Annu Rev Clin Psychol 2020;16:187–212.

[68] van Vliet CM, Meulders A, Vancleef LMG, Vlaeyen JWS. The Opportunity to Avoid Pain May Paradoxically Increase Fear. The Journal of Pain 2018;19:1222–1230.

[69] Wall PD. On the relation of injury to pain the John J. Bonica Lecture. PAIN 1979;6:253–264.

Figure 1. ***Schematic of the differences between the standard acute/chronic pain distinction and the basic exploration-exploitation model.*** *A) According to the standard acute/chronic pain dichotomy, following an injury, the individual experiences acute pain, where avoidance is largely adaptive. If that pain persists for more than 3 months, then acute pain transforms to chronic pain and adaptive avoidance to maladaptive. B) Example visualization of the EED decision process. In it, an individual enters a loop where they encounter different states. Based on the (prior) knowledge that the individual has they need to balance between exploration and exploitation and perform an action (here running). After the action, an outcome is observed (here pain or no pain) after which the individual enters the next state, and a similar procedure is followed. See main text for more information.*



A)
Injury
Healthy
Acute
Pain
(Adaptive Avoidance)
Chronic
Pain
(Maladaptive Avoidance)
Time
B)
Individual
State
Exploration vs.
Exploitation
Action
Pain
No
Pain