**Supplementary Material**

**New directions in predictive processing**

***Mind & Language***

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*Supplementary Table S1*: Overview of recent philosophically oriented predictive processing research\*

|  |  |  |
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| Predictive coding, approximate inference; the predictive processing toolbox | | |
| Introductions | Selection of introductions; history; tutorials; overviews | ([Bogacz, 2017](#_ENREF_23), [Buckley et al., 2017](#_ENREF_33), [Wiese and Metzinger, 2017](#_ENREF_291), [Aitchison and Lengyel, 2017](#_ENREF_1), [Hatfield, 2002](#_ENREF_114), [Kwisthout et al., 2017](#_ENREF_177), [Ostwald et al., 2014](#_ENREF_207), [Swanson, 2016](#_ENREF_259), [Hohwy, 2007](#_ENREF_122), [de Lange et al., 2018](#_ENREF_71)) |
| 20th Century approaches | Predictive coding, cybernetics, perceptual inference, forward modelling, generative models | ([Barlow, 1958](#_ENREF_18), [Craik, 1943](#_ENREF_67), [Ashby, 1947](#_ENREF_11), [Powers, 1973](#_ENREF_222), [Neisser, 1967](#_ENREF_202), [Rock, 1983](#_ENREF_236), [Gregory, 1980](#_ENREF_109), [Mumford, 1992](#_ENREF_201), [Hinton and Sejnowski, 1983](#_ENREF_117), [Frith, 1992](#_ENREF_96), [Seth, 2015a](#_ENREF_244), [Dayan et al., 1995](#_ENREF_69)); see also ([Williams, 2018d](#_ENREF_298)) |
| Contemporary approaches | Predictive processing; philosophical treatments; commentaries | ([Clark, 2013](#_ENREF_45)) including Commentaries as well as additional Commentaries in the *Frontiers* Research Topic on *Forethought as an evolutionary doorway to emotions and consciousness*, and Clark’s responses in both *Behavioural & Brain Science* and *Frontiers*. ([Hohwy, 2013](#_ENREF_126), [Hohwy, 2010](#_ENREF_123), [Clark, 2016](#_ENREF_49)) |
|  | Variants and alternatives | ([Spratling, 2010](#_ENREF_253), [Spratling, 2017](#_ENREF_254), [Heeger, 2017](#_ENREF_115), [Lee and Mumford, 2003](#_ENREF_181), [van der Helm, 2016](#_ENREF_267), [Radulescu et al., 2019](#_ENREF_225), [Grush, 2004](#_ENREF_110), [Eliasmith, 2003](#_ENREF_81), [Fazelpour and Thompson, 2015](#_ENREF_87), [Carhart-Harris et al., 2014](#_ENREF_38), [Keller and Mrsic-Flogel, 2018](#_ENREF_151)) |
|  | Bayesian brain; prospective brain | ([Chater et al., 2006](#_ENREF_40), [Tenenbaum et al., 2011](#_ENREF_261), [Rao et al., 2002](#_ENREF_232), [Knill and Richards, 1996](#_ENREF_171), [Bar, 2011](#_ENREF_17), [Frith, 2007](#_ENREF_97), [Rescorla, 2015](#_ENREF_234), [Lauwereyns, 2012](#_ENREF_179)) |
|  | Bayes; criticism | ([Jones and Love, 2011](#_ENREF_149), [Colombo and Hartmann, 2017](#_ENREF_59), [Klein, 2016](#_ENREF_170), [Colombo et al., 2018](#_ENREF_58), [Rahnev and Denison, 2018](#_ENREF_226)) |
|  | Dark room problem; novelty | ([Hohwy, 2015b](#_ENREF_129), [Friston et al., 2012](#_ENREF_93), [Sims, 2017](#_ENREF_251), [Fink and Zednik, 2017](#_ENREF_89), [Kiverstein et al., 2017](#_ENREF_169), [Venter, 2016](#_ENREF_275)) |
|  | Free energy principle | ([Friston, 2010](#_ENREF_90), [Hohwy, 2018a](#_ENREF_135), [Ramstead et al., 2019a](#_ENREF_227), [Allen, 2018](#_ENREF_3), [Allen and Friston, 2018](#_ENREF_4), [Clark, 2016: Appendix](#_ENREF_49), [Hohwy, in prep.](#_ENREF_137), [Colombo and Wright, 2018](#_ENREF_61), [Colombo and Wright, 2017](#_ENREF_60), [Kirchhoff, 2015](#_ENREF_162), [Baltieri and Buckley, 2019](#_ENREF_16), [Hohwy, 2015b](#_ENREF_129)) |
| Predictive processing in philosophy of perception, cognition and action | | |
| Perceptual and active inference | Binocular rivalry; explanatory strength and scope | ([Block, 2018](#_ENREF_22), [Block, 2015](#_ENREF_21), [Haas, in prep.](#_ENREF_111), [Hohwy et al., 2008](#_ENREF_141), [Clark, 2013](#_ENREF_45)) |
|  | Binocular rivalry; empirical evidence and models | ([Weilnhammer et al., 2017](#_ENREF_280), [Weilnhammer et al., 2018](#_ENREF_281), [Parr et al., 2019](#_ENREF_211)) |
|  | Illusions; visual, multisensory, Bayesian approaches | ([Brown and Friston, 2012](#_ENREF_27), [Hohwy and Paton, 2010](#_ENREF_139), [Hohwy, 2013](#_ENREF_126), [Trommershäuser et al., 2011](#_ENREF_263), [Alais and Burr, 2004](#_ENREF_2)) |
| Precision optimization | Precision; inference and optimization; hierarchical filtering | ([Hohwy, 2012](#_ENREF_125), [Clark, 2013](#_ENREF_45), [Clark, 2016](#_ENREF_49), [Hohwy, 2017b](#_ENREF_134), [Mathys et al., 2014](#_ENREF_196), [Heilbron and Meyniel, 2019](#_ENREF_116)) |
|  | Precision; attention as precision optimisation | ([Ransom et al., 2017](#_ENREF_231), [Clark, 2017c](#_ENREF_52), [Feldman and Friston, 2010](#_ENREF_88), [Hohwy, 2012](#_ENREF_125)) |
|  | Precision; precision and affordance | ([Miller and Clark, 2017](#_ENREF_199), [Clark, 2016](#_ENREF_49)) |
|  | Precision; sensory attenuation | ([Brown et al., 2013](#_ENREF_26), [Laak et al., 2017](#_ENREF_178), [Vasser et al., 2019](#_ENREF_273), [Van Doorn et al., 2015](#_ENREF_268), [Wiese, 2017a](#_ENREF_285)) |
| Action | Action; and the free energy principle | ([Hohwy, 2018a](#_ENREF_135), [Hohwy, 2016a](#_ENREF_131), [Clark, 2019a](#_ENREF_55), [Limanowski, 2017](#_ENREF_183), [Clark, 2015a](#_ENREF_47)) |
|  | Action and PP | ([Klein, 2016](#_ENREF_170), [Vance, 2017](#_ENREF_271), [Bruineberg, 2017](#_ENREF_28), [Burr, 2017](#_ENREF_35), [Kirchhoff, 2018a](#_ENREF_158), [Clark, 2019a](#_ENREF_55), [Wiese, 2014](#_ENREF_283), [Seth, 2015b](#_ENREF_245)) |
|  | Mental action | ([Metzinger, 2017](#_ENREF_197)) |
|  | Sense of agency | ([Kahl and Kopp, 2018](#_ENREF_150), [Hohwy, 2016a](#_ENREF_131)) |
| Perception and cognition | Cognitive penetrability; different approaches | ([Lupyan, 2015](#_ENREF_189), [Marchi, 2017](#_ENREF_195), [Vetter and Newen, 2014](#_ENREF_276), O’Callaghan et al., 2017) |
|  | Cognitive penetrability; critical treatments | ([Macpherson, 2017](#_ENREF_191), [Jenkin and Siegel, 2015](#_ENREF_147), [Vance, 2014](#_ENREF_269), [Vance and Stokes, 2017](#_ENREF_272)) |
|  | High level properties in perception | ([Vance, 2015](#_ENREF_270), [Siegel, 2017](#_ENREF_248), [Clark, 2012](#_ENREF_44), [Hohwy, 2013: Ch 1](#_ENREF_126)) |
|  | Rationality of perception | ([Siegel, 2018](#_ENREF_249), [Siegel, 2017](#_ENREF_248), Gładziejewski, 2017) |
|  | Perception and thought | ([Williams, 2018c](#_ENREF_297), [Pezzulo, 2017](#_ENREF_219), [Butz, 2017](#_ENREF_36), [Williams, 2019a](#_ENREF_300)) |
| Perceptual structure and phenomenology | Sense of presence | ([Seth, 2014](#_ENREF_243), [Hohwy, 2014](#_ENREF_127), [Limanowski and Friston, 2018](#_ENREF_185), [Sato, 2016](#_ENREF_237), [Wiese, 2015](#_ENREF_284), [Seth et al., 2012](#_ENREF_247)) |
|  | Poverty/richness of perception | ([Sato, 2016](#_ENREF_237)) |
|  | Sense of particularity | ([Sato, 2016](#_ENREF_237)) |
|  | Personhood | ([Sato, 2016](#_ENREF_237)) |
|  | Imagery | ([Kirchhoff, 2018d](#_ENREF_164), [Clark, 2014](#_ENREF_46)) |
|  | Meditation | ([Lutz et al., 2019](#_ENREF_190)) |
|  | Absence perception | ([Farennikova, 2014](#_ENREF_86)) |
|  | Dreaming | ([Windt, 2018](#_ENREF_305), [Hobson and Friston, 2012](#_ENREF_120), [Bucci and Grasso, 2017](#_ENREF_32), [Hobson and Friston, 2014](#_ENREF_119)) |
|  | Supernatural agency experiences | ([Andersen, 2017](#_ENREF_6), [Hohwy and Paton, 2010](#_ENREF_139)) |
|  | Phenomenal unity | ([Wiese, 2018](#_ENREF_288)) |
|  | Art and music perception | ([Van de Cruys and Wagemans, 2011](#_ENREF_266), [Michael and Wolf, 2017](#_ENREF_198), [Koelsch et al., 2019](#_ENREF_172), [Vuust and Witek, 2014](#_ENREF_278)) |
|  | Temporal perception | ([Hohwy et al., 2016](#_ENREF_140), [Wiese, 2017b](#_ENREF_286), [Kent et al., 2019](#_ENREF_152), [Sato, 2016](#_ENREF_237), [Vogel et al., 2018](#_ENREF_277)) |
| Cognitive aspects | PP and folk psychology | ([Dewhurst, 2017](#_ENREF_73)) |
|  | Modularity | ([Hohwy, 2013: Ch 7](#_ENREF_126), [Drayson, 2017](#_ENREF_78)) |
|  | Language | ([Pickering and Clark, 2014](#_ENREF_220)) |
|  | Reading | ([Fabry, 2017a](#_ENREF_82)) |
|  | Self-deception | ([Pliushch, 2017](#_ENREF_221)) |
|  | Culture | ([Ramstead et al., 2016](#_ENREF_230), [Veissière et al., 2019](#_ENREF_274), [Fabry, 2018](#_ENREF_84), [Maiese, 2019](#_ENREF_194)) |
| Interoception, bodily sensation, emotion | Emotion | ([Hohwy, 2011](#_ENREF_124), [Barrett, 2016](#_ENREF_19), [Van de Cruys, 2017](#_ENREF_264), [Wilkinson et al., 2019](#_ENREF_293)) |
|  | Pain | ([Fardo et al., 2017](#_ENREF_85)) |
|  | Interoception; brain-body coupling | ([Quadt et al., 2018](#_ENREF_223), [Seth and Friston, 2016](#_ENREF_246), [Stephan et al., 2016](#_ENREF_257), [Seth, 2013](#_ENREF_242), [Gallagher and Allen, 2018](#_ENREF_99), [Allen and Friston, 2018](#_ENREF_4), [Hohwy, 2011](#_ENREF_124), [Allen et al., 2019](#_ENREF_5)) |
| Self and consciousness | Self | ([Apps and Tsakiris, 2014](#_ENREF_9), [Limanowski and Blankenburg, 2013](#_ENREF_184), [Gerrans, 2018](#_ENREF_102), [Letheby and Gerrans, 2017](#_ENREF_182), [Schlicht, 2017](#_ENREF_238), Woźniak, 2018, [Ciaunica and Fotopoulou, 2016](#_ENREF_43), [Hohwy and Michael, 2017](#_ENREF_138), [Moutoussis et al., 2014](#_ENREF_200), [Gerrans, 2015b](#_ENREF_101), [Gerrans, 2015a](#_ENREF_100), [Lin, 2015](#_ENREF_186), [Kiverstein, 2018](#_ENREF_168), [Wiese and Metzinger, in press](#_ENREF_290), [Wiese, forthcoming](#_ENREF_289), [Schlicht and Venter, 2019](#_ENREF_239)) |
|  | Consciousness | ([Hohwy et al., 2008](#_ENREF_141), [Williford et al., 2018](#_ENREF_304), [Solms and Friston, 2018](#_ENREF_252), [Dolega and Dewhurst, 2015](#_ENREF_75), [Hohwy, 2015c](#_ENREF_130), [Kirchhoff and Kiverstein, 2019a](#_ENREF_160), [Clark et al., 2019](#_ENREF_57), [Williford, 2017](#_ENREF_303), [Dolega and Dewhurst, 2019](#_ENREF_76), [Whyte, 2019](#_ENREF_282), [Clark, 2019b](#_ENREF_56)) |
| Mental disorder | Delusion | ([Frith, 1992](#_ENREF_96), [Davies and Coltheart, 2000](#_ENREF_68), [Hohwy, 2004](#_ENREF_121), [Hohwy and Rosenberg, 2005](#_ENREF_142), [Bortolotti and Miyazono, 2015](#_ENREF_25), [Parrott, 2019](#_ENREF_214), [Williams, 2018a](#_ENREF_295), [Tappin and Gadsby, 2019](#_ENREF_260), [Corlett, 2019](#_ENREF_65)) |
|  | Hallucinations | ([Corlett et al., 2019](#_ENREF_66), [Wilkinson, 2014](#_ENREF_292)) |
|  | Psychosis in general | ([Sterzer et al., 2018](#_ENREF_258)) |
|  | Depression; anxiety; stress | ([Badcock et al., 2017](#_ENREF_14), [Peters et al., 2017](#_ENREF_218)) |
|  | Autism; perceptual inference | ([Pellicano and Burr, 2012](#_ENREF_215), [Lawson et al., 2014](#_ENREF_180), [Van de Cruys et al., 2014](#_ENREF_265)) |
|  | Autism; active inference | ([Palmer et al., 2017](#_ENREF_209), [Perrykkad and Hohwy, 2020](#_ENREF_217)) |
|  | Autism; social cognition | ([Kilner et al., 2007](#_ENREF_157), [Palmer et al., 2015](#_ENREF_210), [Quadt, 2017](#_ENREF_224)) |
|  | Autism; self | ([Constant et al., 2018a](#_ENREF_62), [Perrykkad and Hohwy, 2019](#_ENREF_216)) |
|  | Trauma | ([Wilkinson et al., 2017](#_ENREF_294)) |
|  | Eating disorders | ([Gadsby and Hohwy, In print.](#_ENREF_98)) |

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| Predictive processing and topics in cognitive science | | |
| Representation | Structural representation; isomorphism; connectionism; knowledge | (Gładziejewski, 2016, Gładziejewski and Miłkowski, 2017, [Williams, 2019b](#_ENREF_301), [Dolega, 2017](#_ENREF_74), [Wiese, 2017c](#_ENREF_287), [Kiefer, 2019](#_ENREF_153), [Williams and Colling, 2018](#_ENREF_302), [Kiefer and Hohwy, 2018](#_ENREF_154), [Ramstead et al., 2019c](#_ENREF_229), [Ghijsen, 2018](#_ENREF_103)) |
|  | Misrepresentation | ([Kiefer and Hohwy, in press](#_ENREF_155), [Kirchhoff and Robertson, 2018](#_ENREF_167), [Loughlin, 2016](#_ENREF_188), [Williams, 2018b](#_ENREF_296), [Kiefer and Hohwy, 2018](#_ENREF_154)) |
|  | Inference and representation in the brain | ([Kiefer, 2017](#_ENREF_156), [Thomson and Piccinini, 2018](#_ENREF_262), [Hipolito, 2019](#_ENREF_118)) |
|  | Bayesian blur | ([Block, 2018](#_ENREF_22), [Madary, 2013](#_ENREF_192), [Clark, 2018a](#_ENREF_53), [Madary, 2017](#_ENREF_193)) |
| 4E (extended, enactive, embedded, extended) cognition | PP conforms to 4E cognition without representation | ([Gallagher and Allen, 2018](#_ENREF_99), [Hutto, 2018](#_ENREF_145), [Fabry, 2017a](#_ENREF_82), [Downey, 2017](#_ENREF_77), [Bruineberg et al., 2018a](#_ENREF_29), [Burr and Jones, 2016](#_ENREF_34), [Burr, 2017](#_ENREF_35), [Kirchhoff and Robertson, 2018](#_ENREF_167), [Hutto and Myin, 2017](#_ENREF_144), [Bruineberg and Rietveld, 2014](#_ENREF_30), [Kirchhoff, 2018b](#_ENREF_159), [Korbak, 2019](#_ENREF_176)) |
|  | PP; threat to 4E cognition | ([Anderson, 2017](#_ENREF_8), [Anderson and Chemero, 2013](#_ENREF_7), [Zahavi, 2017](#_ENREF_307)) |
|  | PP; fits 4E cognition (with representation) | ([Clark, 2017b](#_ENREF_51), [Clark, 2017a](#_ENREF_50), [de Bruin and Michael, 2017](#_ENREF_70), [Clark, 2015b](#_ENREF_48), [Linson et al., 2018](#_ENREF_187), [Clark, 2018b](#_ENREF_54), [Ramstead et al., 2019b](#_ENREF_228)) |
|  | PP; is internalist; accommodates 4E insights | ([Hohwy, 2017a](#_ENREF_133), [Hohwy, 2016b](#_ENREF_132), [Hohwy, 2018b](#_ENREF_136)), for discussion, see ([Bruineberg et al., 2018a](#_ENREF_29), [Bruineberg and Rietveld, 2014](#_ENREF_30), [Clark, 2017a](#_ENREF_50), [Fabry, 2017b](#_ENREF_83), [Williams, 2018e](#_ENREF_299)) |
|  | Direct perception; Gibsonian topics | ([Drayson, 2018](#_ENREF_79), [Orlandi, 2016](#_ENREF_205), [Orlandi, 2014](#_ENREF_204), [Orlandi, 2018](#_ENREF_206)) |
|  | Markov blankets | ([Ramstead et al., 2019b](#_ENREF_228), [Hohwy, 2016b](#_ENREF_132), [Kirchhoff et al., 2018](#_ENREF_161), [Palacios et al., 2017](#_ENREF_208), [Kirchhoff and Kiverstein, 2019b](#_ENREF_166)) |
| Biology | Life and self-evidencing | ([Hohwy, 2016b](#_ENREF_132), [Friston, 2013](#_ENREF_91), [Constant et al., 2018b](#_ENREF_63), [Ramstead et al., 2019a](#_ENREF_227), [Kirchhoff, 2018c](#_ENREF_163)) |
|  | Agent and niche | ([Bruineberg et al., 2018b](#_ENREF_31)) |
|  | Homeostasis and allostasis | ([Corcoran and Hohwy, 2018](#_ENREF_64)) |
|  | Evolution | ([Badcock et al., 2019](#_ENREF_15), [Badcock, 2012](#_ENREF_13)) |
|  | Scope of cognition | ([Sims, 2016](#_ENREF_250), [Calvo and Friston, 2017](#_ENREF_37), [Kirchhoff, 2018c](#_ENREF_163), [Sims, 2017](#_ENREF_251), [Kirchhoff and Froese, 2017](#_ENREF_165)) |
| The philosophy of science of predictive processing | | |
| Evidence and falsifiability | FEP and falsifiability | ([Colombo and Wright, 2018](#_ENREF_61), [Allen, 2018](#_ENREF_3), [Hohwy, 2015b](#_ENREF_129)) |
|  | Deviant priors; complete class theorems | ([Wald, 1947](#_ENREF_279), [Friston et al., 2017](#_ENREF_95), [Parr et al., 2018](#_ENREF_213)) |
| Some examples of empirical evidence in cognitive neuroscience | Predictive coding predicts neurons do not bifurcate; cortical responses in general | ([Friston, 2018](#_ENREF_92), [Friston, 2005](#_ENREF_94)) |
|  | Expected but absent input generates ascending prediction error | ([den Ouden et al., 2009](#_ENREF_72), [Chennu et al., 2016](#_ENREF_41)) |
|  | Predictions modulate low level sensory activity | ([Kok et al., 2017](#_ENREF_174), [Kok and de Lange, 2014](#_ENREF_173), [Edwards et al., 2017](#_ENREF_80), [Aru et al., 2016](#_ENREF_10)) |
|  | Neuronal evidence of prediction error computation | ([Schwiedrzik and Freiwald, 2017](#_ENREF_241)) |
|  | Precision-weighted predictive coding; volatility prediction; feature-based prediction errors | ([Iglesias et al., 2013](#_ENREF_146), [Stefanics et al., 2018](#_ENREF_255), [Stefanics et al., 2019](#_ENREF_256)) |
|  | Hierarchical predictive coding | ([Chao et al., 2018](#_ENREF_39)) |
|  | Distinct pathways for expectation and attention | ([Kok et al., 2012](#_ENREF_175), [Gordon et al., 2019](#_ENREF_108)) |
|  | Repetition suppression; context-dependence | ([Auksztulewicz and Friston, 2016](#_ENREF_12)) |
|  | EEG; N170 signals precision-weighted prediction errors | ([Johnston et al., 2017](#_ENREF_148), [Robinson et al., 2018](#_ENREF_235)) |
|  | Binocular rivalry; prediction error accumulation for the suppressed stimulus | ([Weilnhammer et al., 2017](#_ENREF_280), [Weilnhammer et al., 2018](#_ENREF_281)) |
|  | Sensory attenuation; precision optimisation not corollary discharge | ([Vasser et al., 2019](#_ENREF_273), [Van Doorn et al., 2015](#_ENREF_268)) |
|  | Precision-weighting in active inference; limited offer games | ([Schwartenbeck et al., 2014](#_ENREF_240)) |
| Mechanistic approaches; unification | Inference and anatomy | ([Parr and Friston, 2018](#_ENREF_212)) |
|  | Mechanisms; computational approaches; unification | ([Boone and Piccinini, 2016](#_ENREF_24), [Chirimuuta, 2017](#_ENREF_42), [Rescorla, 2014](#_ENREF_233), [Harkness and Keshava, 2017](#_ENREF_113), [Hohwy, 2015a](#_ENREF_128), [Harkness, 2015](#_ENREF_112), [Beni, 2018](#_ENREF_20), [Colombo and Wright, 2017](#_ENREF_60), [Hutchinson and Barrett, 2019](#_ENREF_143), Gładziejewski, 2019) |

*Supplementary Table S1: Overview of recent philosophically oriented predictive processing research. A selective sample taken mid-2019, based on a manual search of research on ‘predictive processing’ and ‘prediction error minimisation’; focused on research published by philosophers, or in philosophy journals, or on philosophical topics. In addition, some references to introductory papers, tutorials, historical sources, and a limited, illustrative sample of empirical work illustrating connections to philosophical debates. The Table includes research where the main focus is predictive processing, mostly excluding research where predictive processing is a subtheme. Apologies for any omissions.*

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