Online Supplementary materials

Table S1: rTMS effects in clinical populations (after Wassermann and Zimmermann, 2012)

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| Population | Effects |
| Depression | rTMS at DLPFC yields a medium to large effect size on reducing the severity of depressive symptoms. |
| Schizophrenia | Low-frequency rTMS significantly reduces intensity of auditory hallucinations but is less efficient in improving negative symptoms. |
| Obsessive compulsive disorder (OCD) | High-frequency rTMS may reduce compulsions; the finding has not been replicated consistently across studies. |
| Posttraumatic stress disorder (PTSD) | High-frequency rTMS may have positive and sustainable therapeutic effects on anxiety. |
| Parkinson’s Disease (PD) | High-frequency rTMS may have beneficial effects on motor disorders |
| Alzheimer disease (AD) | High-frequency, offline rTMS may contribute to small short-term improvement in cognitive functioning |

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| Table S2: Search syntax**AMED (Allied and Complementary Medicine) 1985 to May 2016** |
| **#** | **Searches** | **Results** |
| **1** | transcranial magnetic stimulation.mp. | 287 |
| **2** | TMS.mp. | 116 |
| **3** | Theory of mind.mp. | 56 |
| **4** | ToM.mp. | 25 |
| **5** | mentali\*.mp. | 20 |
| **6** | role taking.mp. | 3 |
| **7** | perspective taking.mp. | 5 |
| **8** | empathy.mp. | 343 |
| **9** | 1 or 2 | 313 |
| **10** | 3 or 4 or 5 or 6 or 7 or 8 | 429 |
| **11** | **9 and 10** | **1** |

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| **Cochrane Library: Issue 4 of 12, April 2016; Cochrane Central Register of Controlled** |
| **#** | **Searches** | **Results** |
| #1 | transcranial magnetic stimulation | 2024 |
| #2 | TMS | 796 |
| #3 | Theory of mind | 659 |
| #4 | ToM | 164 |
| #5 | mentali\* | 96 |
| #6 | role taking | 800 |
| #7 | perspective taking | 176 |
| #8 | empath\* | 453 |
| #9 | #1 or #2 | 2235 |
| #10 | #3 or #4 or #5 or #6 or #7 or #8  | 2233 |
| #11 | #9 and #10  | 6 |

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| **OVID: Embase 1980 to 2016 Week 21** |
| **#** | **Searches** | **Results** |
| **1** | transcranial magnetic stimulation.mp. | 18219 |
| **2** | TMS.mp. | 12740 |
| **3** | Theory of mind.mp. | 4908 |
| **4** | ToM.mp. | 3625 |
| **5** | mentali\*.mp. | 3749 |
| **6** | role taking.mp. | 164 |
| **7** | perspective taking.mp. | 1354 |
| **8** | empath\*.mp. | 23301 |
| **9** | 1 or 2 | 23283 |
| **10** | 3 or 4 or 5 or 6 or 7 or 8  | 33707 |
| **11** | **9 and 10** | **128** |
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| **OVID MEDLINE(R) 1946 to May Week 2 2016** |
| **#** | **Searches** | **Results** |
| **1** | transcranial magnetic stimulation.mp. | 10734 |
| **2** | TMS.mp. | 7672 |
| **3** | Theory of mind.mp. | 3010 |
| **4** | ToM.mp. | 2291 |
| **5** | mentali\*.mp. | 2406 |
| **6** | role taking.mp. | 151 |
| **7** | perspective taking.mp. | 857 |
| **8** | empath\*.mp. | 18755 |
| **9** | 1 or 2 | 13734 |
| **10** | 3 or 4 or 5 or 6 or 7 or 8  | 25376 |
| **11** | **9 and 10** | **59** |

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| **OVID: PsycINFO 1806 to May Week 3 2016** |
| **#** | **Searches** | **Results** |
| **1** | transcranial magnetic stimulation.mp. | 7371 |
| **2** | TMS.mp. | 3724 |
| **3** | Theory of mind.mp. | 7047 |
| **4** | ToM.mp. | 3343 |
| **5** | mentali\*.mp. | 5698 |
| **6** | role taking.mp. | 2669 |
| **7** | perspective taking.mp. | 3265 |
| **8** | empath\*.mp. | 26113 |
| **9** | 1 or 2 | 7824 |
| **10** | 3 or 4 or 5 or 6 or 7 or 8 | 42782 |
| **11** | **9 and 10** | **65** |
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| **Pubmed 25052016** |
| **#** | **Searches** | **Results** |
| #1 | Search (transcranial magnetic stimulation) OR TMS | 16057 |
| #2 | Search **(((((theory of mind) OR mentali\*) OR empath\*) OR perspective taking) OR role taking) OR ToM** | 61634 |
| #3 | Search (#1) AND #2 | 131 |

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| **Web of Science Core Collection: Citation Indexes: Science Citation Index Expanded (SCI-EXPANDED) --1900-present; Social Sciences Citation Index (SSCI) --1956-present; Arts & Humanities Citation Index (A&HCI) --1975-present; Conference Proceedings Citation Index- Science (CPCI-S) --1990-present; Conference Proceedings Citation Index- Social Science & Humanities (CPCI-SSH) --1990-present** |
| **#** | **Searches** | **Results** |
| #1 | "transcranial magnetic stimulation" | 16137 |
| #2 | TMS | 13326 |
| #3 | "Theory of mind" | 5489 |
| #4 | ToM | 10802 |
| #5 | mentali\* | 6906 |
| #6 | "role taking" | 436 |
| #7 | "perspective taking" | 3171 |
| #8 | empath\* | 18938 |
| #9 | #1 or #2 | 23415 |
| #10 | #3 or #4 or #5 or #6 or #7 or #8  | 41869 |
| #11 | #9 and #10  | 116 |

Table S3: The list of the excluded studies

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| **Excluded due to the type of publication** |
| Agnew, Z. K., Bhakoo, K. K., & Puri, B. K. (2007). The human mirror system: A motor resonance theory of mind-reading. Brain Research Reviews, 54(2), 286-293. doi: 10.1016/j.brainresrev.2007.04.003 |
| Andrews, S. C., Enticott, P. G., Hoy, K. E., & Fitzgerald, P. B. (2013). Mirror systems and social cognition in schizophrenia. Schizophrenia Bulletin, 39, S218. doi: http://dx.doi.org/10.1093/schbul/sbt011 |
| Avenanti, A. (2010). Neurophysiological markers of empathy for pain. European Journal of Neurology, 17, 10. doi: http://dx.doi.org/10.1111/j.1468-1331.2010.03230.x |
| Avenanti, A., Candidi, M., & Urgesi, C. (2013). Vicarious motor activation during action perception: beyond correlational evidence. Frontiers in Human Neuroscience, 7. doi: 10.3389/fnhum.2013.00185 |
| Avenanti, A., & Urgesi, C. (2011). Understanding 'what' others do: mirror mechanisms play a crucial role in action perception. Social Cognitive and Affective Neuroscience, 6(3), 257-259. doi: 10.1093/scan/nsr004 |
| Baeken, C. (2011). One left-sided dorsolateral prefrontal cortical HF-rTMS session affects emotional neuronal processing in healthy women. Clinical Neurophysiology, 122, S144-S145. doi: http://dx.doi.org/10.1016/S1388-2457%2811%2960516-6 |
| Baeken, C., Van Schuerbeek, P., De Raedt, R., De Mey, J., Vanderhasselt, M. A., Santermans, L., . . . Luypaert, R. (2011). The effect of one left-sided prefrontal HF-rTMS session on emotional brain processes. European Psychiatry, 26. doi: http://dx.doi.org/10.1016/S0924-9338%2811%2972838-3 |
| Balconi, M., & Canavesio, Y. (2013). High-frequency rTMS stimulation improves the facial mimicry and detection responses in an empathic emotional task. Clinical Neurophysiology, 124 (10), e115-e116. doi: http://dx.doi.org/10.1016/j.clinph.2013.04.184 |
| Balconi, M., & Canavesio, Y. (2013). rTMS stimulation improves the facial mimicry and detection responses in an empathic emotional task. Behavioural Neurology, 27 (3), 418. doi: http://dx.doi.org/10.3233/BEN-139900 |
| Bernhardt, B. C., & Singer, T. (2012). The neural basis of empathy (pp. 1-23). 4139 El Camino Way, P.O. Box 10139, Palo Alto CA 94306, United States: Annual Reviews Inc. |
| Bernier, R., & Dawson, G. (2009). The role of mirror neuron dysfunction in autism Mirror neuron systems: The Role of Mirroring Processes in Social Cognition (pp. 261-286). Totowa, NJ: Humana Press; US. |
| Bouaziz, N., Benadhira, R., Sidhoumi, D., & Januel, D. (2011). Transcranial magnetic stimulation (rTMS) concerning the treatment of schizophrenia: Interests and perspectives. Annales Medico-Psychologiques, 169(3), 192-195. doi: http://dx.doi.org/10.1016/j.amp.2011.02.013 |
| Christov-Moore, L., Simpson, E. A., Coude, G., Grigaityte, K., Iacoboni, M., & Ferrari, P. F. (2014). Empathy: Gender effects in brain and behavior. Neuroscience and Biobehavioral Reviews, 46(P4), 604-627. doi: http://dx.doi.org/10.1016/j.neubiorev.2014.09.001 |
| Cooper, N. R., Puzzo, I., & Pawley, A. D. (2008). Contagious yawning: The mirror neuron system may be a candidate physiological mechanism. Medical Hypotheses, 71(6), 975-976. doi: http://dx.doi.org/10.1016/j.mehy.2008.07.023 |
| Corbetta, M., Patel, G., & Shulman, G. L. (2008). The Reorienting System of the Human Brain: From Environment to Theory of Mind. Neuron, 58(3), 306-324. doi: http://dx.doi.org/10.1016/j.neuron.2008.04.017 |
| Demirtas-Tatlidede, A., & Schmahmann, J. D. (2013). Morality: Incomplete without the cerebellum? Brain, 136(8), e244. doi: http://dx.doi.org/10.1093/brain/awt070 |
| Enticott, P. G., Kennedy, H. A., Rinehart, N. J., May, S., Rossell, S., Tonge, B. J., . . . Fitzgerald, P. B. (2011). Social cognitive impairments in autism spectrum disorders: Insights from neuropsychiatry. Clinical EEG and Neuroscience, 42 (2), 130.  |
| Fumagalli, M., & Priori, A. (2012). Functional and clinical neuroanatomy of morality. Brain, 135(Pt 7), 2006-2021. doi: http://dx.doi.org/10.1093/brain/awr334 |
| Hetu, S., Taschereau-Dumouchel, V., & Jackson, P. L. (2012). Stimulating the brain to study social interactions and empathy. Brain Stimulation, 5(2), 95-102. doi: http://dx.doi.org/10.1016/j.brs.2012.03.005 |
| Iacoboni, M. (2012). The human mirror neuron system and its role in imitation and empathy The primate mind: Built to connect with other minds (pp. 32-47). Cambridge, MA: Harvard University Press; US. |
| Iacoboni, M., & Dapretto, M. (2006). The mirror neuron system and the consequences of its dysfunction. Nature Reviews Neuroscience, 7(12), 942-951. doi: http://dx.doi.org/10.1038/nrn2024 |
| Jankowiak-Siuda, K., Siemieniuk, K., & Grabowska, A. (2009). Neurobiological basis of empathy. [Polish] |
| Neurobiologiczne podstawy empatii. Neuropsychiatria i Neuropsychologia, 4(2), 51-58.  |
| Krippl, M., & Karim, A. A. (2011). "EuroTheory of mind" and its neuronal correlates in forensically relevant disorders. Nervenarzt, 82(7), 843-852. doi: 10.1007/s00115-010-3073-x |
| Li, H., Wang, J., Li, C., & Xiao, Z. (2014). Repetitive transcranial magnetic stimulation (rTMS) for panic disorder in adults. Cochrane Database of Systematic Reviews, (9). http://onlinelibrary.wiley.com/doi/10.1002/14651858.CD009083.pub2/abstract doi:10.1002/14651858.CD009083.pub2 |
| Mak, A. D. P., & Lam, L. C. W. (2013). Neurocognitive profiles of people with borderline personality disorder. Current Opinion in Psychiatry, 26(1), 90-96. doi: http://dx.doi.org/10.1097/YCO.0b013e32835b57a9 |
| Mehta, U. M., Basavaraju, R., Thirthalli, J., & Gangadhar, B. N. (2012). Mirror neuron dysfunction-a neuro-marker for social cognition deficits in drug naive schizophrenia. Biological Psychiatry, 1), 314S. doi: http://dx.doi.org/10.1016/j.biopsych.2012.02.014 |
| Mehta, U. M., Basavaraju, R., Thirthalli, J., & Gangadhar, B. N. (2013). Mirror neuron dysfunction in schizophrenia and its association with social cognition. Schizophrenia Bulletin, 39, S242. doi: http://dx.doi.org/10.1093/schbul/sbt011 |
| Miniussi, C., Cappa, S. F., Cohen, L. G., Floel, A., Fregni, F., Nitsche, M. A., . . . Walsh, V. (2008). Efficacy of repetitive transcranial magnetic stimulation/transcranial direct current stimulation in cognitive neurorehabilitation. Brain Stimul, 1(4), 326-336. doi: 10.1016/j.brs.2008.07.002 |
| Molnar-Szakacs, I. (2011). From actions to empathy and morality - A neural perspective. Journal of Economic Behavior & Organization, 77(1), 76-85. doi: 10.1016/j.jebo.2010.02.019 |
| Newlin, D. B., & Renton, R. M. (2010). A Self in the Mirror: Mirror Neurons, Self-Referential Processing, and Substance Use Disorders. Substance Use and Misuse, 45(11), 1697-1726. doi: 10.3109/10826084.2010.482421 |
| Obhi, S. S., & Sebanz, N. (2011). Moving together: Toward understanding the mechanisms of joint action. Experimental Brain Research, 211(3-4), 329-336. doi: http://dx.doi.org/10.1007/s00221-011-2721-0 |
| O'Malley, M. K., Ro, T., & Levin, H. S. (2006). Assessing and inducing neuroplasticity with transcranial magnetic stimulation and robotics for motor function. Archives of Physical Medicine and Rehabilitation, 87(12 Suppl 2), S59-66. doi: 10.1016/j.apmr.2006.08.332 |
| Perkins, T., Stokes, M., McGillivray, J., & Bittar, R. (2010). Mirror neuron dysfunction in autism spectrum disorders. Journal of Clinical Neuroscience, 17(10), 1239-1243. doi: http://dx.doi.org/10.1016/j.jocn.2010.01.026 |
| Schuwerk, T., Langguth, B., & Sommer, M. (2014). Modulating functional and dysfunctional mentalizing by transcranial magnetic stimulation. Frontiers in Psychology, 5. doi: 10.3389/fpsyg.2014.01309 |
| Singer, T., & Frith, C. (2005). The painful side of empathy. Nature Neuroscience, 8(7), 845-846. doi: http://dx.doi.org/10.1038/nn0705-845 |
| Suttrup, J., Keysers, C., & Thioux, M. (2015). The role of the theory of mind network in action observation-an rTMS study. Brain Stimulation, 8 (2), 415-416.  |
| van Honk, J., & Schutter, D. J. (2006). Unmasking feigned sanity: A neurobiological model of emotion processing in primary psychopathy. Cognitive Neuropsychiatry, 11(3), 285-306. doi: http://dx.doi.org/10.1080/13546800500233728 |
| **Excluded due to no TMS involved after reviewing abstracts** |
| Aziz-Zadeh, L., Sheng, T., & Gheytanchi, A. (2010). Common Premotor Regions for the Perception and Production of Prosody and Correlations with Empathy and Prosodic Ability. PloS One, 5(1). doi: 10.1371/journal.pone.0008759 |
| Benuzzi, F., Lui, F., Duzzi, D., Nichelli, P. F., & Porro, C. A. (2008). Does it look painful or disgusting? Ask your parietal and cingulate cortex. Journal of Neuroscience, 28(4), 923-931. doi: 10.1523/jneurosci.4012-07.2008 |
| Lepage, J.-F. (2011). Developpement et fonctionnement des mecanismes de resonance motrice chez l'humain. Dissertation Abstracts International: Section B: The Sciences and Engineering, 72(4-B), 2475.  |
| Marsh, L. E., Mullett, T. L., Ropar, D., & de, C. (2014). Responses to irrational actions in action observation and mentalising networks of the human brain. Neuroimage, 103, 81-90. doi: http://dx.doi.org/10.1016/j.neuroimage.2014.09.020 |
| Parkinson, C., & Wheatley, T. (2014). Relating Anatomical and Social Connectivity: White Matter Microstructure Predicts Emotional Empathy. Cerebral Cortex, 24(3), 614-625. doi: 10.1093/cercor/bhs347 |
| **Excluded due to intervention (not rTMS) after reviewing abstracts** |
| Andrews, S. C., Enticott, P. G., Hoy, K. E., Thomson, R. H., & Fitzgerald, P. B. (2015). No evidence for mirror system dysfunction in schizophrenia from a multimodal TMS/EEG study. Psychiatry Research. doi: 10.1016/j.psychres.2015.05.067 |
| Andrews, S. C., Enticott, P. G., Hoy, K. E., Thomson, R. H., & Fitzgerald, P. B. (2015). Reduced mu suppression and altered motor resonance in euthymic bipolar disorder: Evidence for a dysfunctional mirror system? Social Neuroscience, 1-12. doi: 10.1080/17470919.2015.1029140 |
| Bolognini, N., Rossetti, A., Fusaro, M., Vallar, G., & Miniussi, C. (2014). Sharing social touch in the primary somatosensory cortex. Current Biology, 24(13), 1513-1517. doi: 10.1016/j.cub.2014.05.025 |
| Borgomaneri, S., Gazzola, V., & Avenanti, A. (2012). Motor mapping of implied actions during perception of emotional body language. Brain Stimulation, 5(2), 70-76. doi: 10.1016/j.brs.2012.03.011 |
| Borgomaneri, S., Gazzola, V., & Avenanti, A. (2014). Temporal dynamics of motor cortex excitability during perception of natural emotional scenes. Social Cognitive and Affective Neuroscience, 9(10), 1451-1457. doi: 10.1093/scan/nst139 |
| Fourkas, A. D., Avenanti, A., Urgesi, C., & Aglioti, S. M. (2006). Corticospinal facilitation during first and third person imagery. Experimental Brain Research, 168(1-2), 143-151. doi: http://dx.doi.org/10.1007/s00221-005-0076-0 |
| Lepage, J. F., Tremblay, S., & Theoret, H. (2010). Early non-specific modulation of corticospinal excitability during action observation. European Journal of Neuroscience, 31(5), 931-937. doi: http://dx.doi.org/10.1111/j.1460-9568.2010.07121.x |
| Liuzza, M. T., Candidi, M., Sforza, A. L., & Aglioti, S. M. (2015). Harm avoiders suppress motor resonance to observed immoral actions. Social Cognitive and Affective Neuroscience, 10(1), 72-77. doi: 10.1093/scan/nsu025 |
| Mahayana, I. T., Banissy, M. J., Chen, C.-Y., Walsh, V., Juan, C.-H., & Muggleton, N. G. (2014). Motor empathy is a consequence of misattribution of sensory information in observers. Frontiers in Human Neuroscience, 8, 47.  |
| Minio-Paluello, I., Baron-Cohen, S., Avenanti, A., Walsh, V., & Aglioti, S. M. (2009). Absence of Embodied Empathy During Pain Observation in Asperger Syndrome. Biological Psychiatry, 65(1), 55-62. doi: http://dx.doi.org/10.1016/j.biopsych.2008.08.006 |
| **Excluded due to outcome (not measuring empathy or ToM) after reviewing abstracts** |
| Basavaraju, R., Mehta, U. M., & Thirthalli, J. (2014). Mirror neuron activity and symptom dimensions in drug-naive mania-a transcranial magnetic stimulation study. Bipolar Disorders, 16, 83-84. doi: http://dx.doi.org/10.1111/bdi.12189 |
| Bolognini, N., Rossetti, A., Maravita, A., & Miniussi, C. (2011). Seeing Touch in the Somatosensory Cortex: ATMS Study of the Visual Perception of Touch. Human Brain Mapping, 32(12), 2104-2114. doi: 10.1002/hbm.21172 |
| Brune, M., Scheele, D., Heinisch, C., Tas, C., Wischniewski, J., & Gunturkun, O. (2012). Empathy Moderates the Effect of Repetitive Transcranial Magnetic Stimulation of the Right Dorsolateral Prefrontal Cortex on Costly Punishment. PloS One, 7(9). doi: http://dx.doi.org/10.1371/journal.pone.0044747 |
| Catmur, C., Walsh, V., & Heyes, C. (2007). Sensorimotor learning configures the human mirror system. Current Biology, 17(17), 1527-1531. doi: 10.1016/j.cub.2007.08.006 |
| Cazzato, V., Mian, E., Serino, A., Mele, S., & Urgesi, C. (2015). Distinct contributions of extrastriate body area and temporoparietal junction in perceiving one's own and others' body. Cognitive Affective & Behavioral Neuroscience, 15(1), 211-228. doi: 10.3758/s13415-014-0312-9 |
| Chiang, T. C., Lu, R. B., Hsieh, S., Chang, Y. H., & Yang, Y. K. (2014). Stimulation in the dorsolateral prefrontal cortex changes subjective evaluation of percepts. PloS One, 9(9), e106943. doi: 10.1371/journal.pone.0106943 |
| Du, D. Q., & Wu, Y. B. (2005). Living ability and cognitive function ameliorated by low frequency repetitive transcranial magnetic stimulation in patients with post-stroke depression: Comparison with drug plus psychological treatment. [Chinese]. Chinese Journal of Clinical Rehabilitation, (16), 22-23. http://onlinelibrary.wiley.com/o/cochrane/clcentral/articles/568/CN-00557568/frame.html |
| Fitzgibbon, B. M., Enticott, P. G., Bradshaw, J. L., Giummarra, M. J., Chou, M., Georgiou-Karistianis, N., & Fitzgerald, P. B. (2012). Enhanced corticospinal response to observed pain in pain synesthetes. Cognitive, Affective and Behavioral Neuroscience, 12(2), 406-418. doi: http://dx.doi.org/10.3758/s13415-011-0080-8 |
| Knoch, D., Gianotti, L. R., Pascual-Leone, A., Treyer, V., Regard, M., Hohmann, M., & Brugger, P. (2006). Disruption of right prefrontal cortex by low-frequency repetitive transcranial magnetic stimulation induces risk-taking behavior. Journal of Neuroscience, 26(24), 6469-6472. doi: 10.1523/jneurosci.0804-06.2006 |
| Novembre, G., Ticini, L., Schutz-Bosbach, S., & Keller, P. (2013). Motor simulation coordinates joint actions in real time: Music performance meets on-line double-pulse TMS. Clinical Neurophysiology, 124 (10), e82. doi: http://dx.doi.org/10.1016/j.clinph.2013.04.116 |
| Novembre, G., Ticini, L. F., Schutz-Bosbach, S., & Keller, P. E. (2012). Distinguishing self and other in joint action. Evidence from a musical paradigm. Cerebral Cortex, 22(12), 2894-2903. doi: http://dx.doi.org/10.1093/cercor/bhr364 |
| Papeo, L., Corradi-Dell'Acqua, C., & Rumiati, R. I. (2011). "She" Is Not Like "I": The Tie between Language and Action Is in Our Imagination. Journal of Cognitive Neuroscience, 23(12), 3939-3948.  |
| Pretalli, J. B., Nicolier, M., Chopard, G., Vandel, P., Tio, G., Monnin, J., . . . Haffen, E. (2012). Resting motor threshold changes and clinical response to prefrontal repetitive transcranial magnetic stimulation in depressed patients. Psychiatry and Clinical Neurosciences, 66(4), 344-352. doi: 10.1111/j.1440-1819.2012.02341.x |
| White, N. C., Reid, C., & Welsh, T. N. (2014). Responses of the human motor system to observing actions across species: A transcranial magnetic stimulation study. Brain and Cognition, 92, 11-18. doi: http://dx.doi.org/10.1016/j.bandc.2014.10.004 |
| **Excluded due to intervention (not rTMS) after reviewing full-texts** |
| Avenanti, A., & Aglioti, S. M. (2006). Pain in the motor system: One study of transcranial magnetic stimulation. Giornale Italiano di Psicologia, 33(4), 777-792.  |
| Avenanti, A., Bueti, D., Galati, G., & Aglioti, S. M. (2005). Transcranial magnetic stimulation highlights the sensorimotor side of empathy for pain. Nature Neuroscience, 8(7), 955-960. doi: 10.1038/nn1481 |
| Avenanti, A., Minio-Paluello, I., Bufalari, I., & Aglioti, S. M. (2006). Stimulus-driven modulation of motor-evoked potentials during observation of others' pain. Neuroimage, 32(1), 316-324. doi: 10.1016/j.neuroimage.2006.03.010 |
| Avenanti, A., Minio-Paluello, I., Bufalari, I., & Aglioti, S. M. (2009). The pain of a model in the personality of an onlooker: Influence of state-reactivity and personality traits on embodied empathy for pain. Neuroimage, 44(1), 275-283. doi: http://dx.doi.org/10.1016/j.neuroimage.2008.08.001 |
| Avenanti, A., Minio-Paluello, I., Sforza, A., & Aglioti, S. M. (2009). Freezing or escaping? Opposite modulations of empathic reactivity to the pain of others. Cortex, 45(9), 1072-1077. doi: http://dx.doi.org/10.1016/j.cortex.2008.10.004 |
| Avenanti, A., Sirigu, A., & Aglioti, S. M. (2010). Racial bias reduces empathic sensorimotor resonance with other-race pain. Current Biology, 20(11), 1018-1022. doi: http://dx.doi.org/10.1016/j.cub.2010.03.071 |
| Borgomaneri, S., Gazzola, V., & Avenanti, A. (2014). Transcranial magnetic stimulation reveals two functionally distinct stages of motor cortex involvement during perception of emotional body language. Brain Structure & Function Jul(Pagination), No Pagination Specified. doi: http://dx.doi.org/10.1007/s00429-014-0825-6 |
| De Coster, L., Andres, M., & Brass, M. (2014). Effects of being imitated on motor responses evoked by pain observation: Exerting control determines action tendencies when perceiving pain in others. The Journal of Neuroscience, 34(20), 6952-6957. doi: http://dx.doi.org/10.1523/JNEUROSCI.5044-13.2014 |
| Donne, C. M., Enticott, P. G., Rinehart, N. J., & Fitzgerald, P. B. (2011). A transcranial magnetic stimulation study of corticospinal excitability during the observation of meaningless, goal-directed, and social behaviour. Neuroscience Letters, 489(1), 57-61. doi: 10.1016/j.neulet.2010.11.067 |
| Enticott, P. G., Harrison, B. A., Arnold, S. L., Nibaldi, K., Segrave, R. A., Fitzgibbon, B. M., . . . Fitzgerald, P. B. (2012). Emotional valence modulates putative mirror neuron activity. Neuroscience Letters, 508(1), 56-59. doi: 10.1016/j.neulet.2011.12.018 |
| Enticott, P. G., Johnston, P. J., Herring, S. E., Hoy, K. E., & Fitzgerald, P. B. (2008). Mirror neuron activation is associated with facial emotion processing. Neuropsychologia, 46(11), 2851-2854. doi: 10.1016/j.neuropsychologia.2008.04.022 |
| Enticott, P. G., Kennedy, H. A., Bradshaw, J. L., Rinehart, N. J., & Fitzgerald, P. B. (2010). Understanding mirror neurons: Evidence for enhanced corticospinal excitability during the observation of transitive but not intransitive hand gestures. Neuropsychologia, 48(9), 2675-2680. doi: 10.1016/j.neuropsychologia.2010.05.014 |
| Enticott, P. G., Kennedy, H. A., Bradshaw, J. L., Rinehart, N. J., & Fitzgerald, P. B. (2011). Motor corticospinal excitability during the observation of interactive hand gestures. Brain Research Bulletin, 85(3-4), 89-95. doi: http://dx.doi.org/10.1016/j.brainresbull.2011.03.018 |
| Fecteau, S., Pascual-Leone, A., & Theoret, H. (2008). Psychopathy and the mirror neuron system: preliminary findings from a non-psychiatric sample. Psychiatry Research, 160(2), 137-144. doi: http://dx.doi.org/10.1016/j.psychres.2007.08.022 |
| Fitzgibbon, B. M., Enticott, P. G., Bradshaw, J. L., Giummarra, M. J., Georgiou-Karistianis, N., Chou, M., & Fitzgerald, P. B. (2012). Motor cortical excitability and inhibition in acquired mirror pain. Neuroscience Letters, 530(2), 161-165. doi: http://dx.doi.org/10.1016/j.neulet.2012.09.036 |
| Guise, K., Kelly, K., Romanowski, J., Vogeley, K., Platek, S. M., Murray, E., & Keenan, J. P. (2007). The anatomical and evolutionary relationship between self-awareness and Theory of mind. Human Nature, 18(2), 132-142. doi: http://dx.doi.org/10.1007/s12110-007-9009-x |
| Lepage, J. F., Lortie, M., Deal, C. L., & Theoret, H. (2014). Empathy, autistic traits, and motor resonance in adults with Turner syndrome. Social Neuroscience, 9(6), 601-609. doi: Doi 10.1080/17470919.2014.944317 |
| Mehta, U. M., Thirthalli, J., Basavaraju, R., Gangadhar, B. N., & Pascual-Leone, A. (2014). Reduced mirror neuron activity in schizophrenia and its association with theory of mind deficits: Evidence from a transcranial magnetic stimulation study. Schizophrenia Bulletin, 40(5), 1083-1094. doi: http://dx.doi.org/10.1093/schbul/sbt155 |
| Minio-Paluello, I., Avenanti, A., & Aglioti, S. M. (2006). Left hemisphere dominance in reading the sensory qualities of others' pain? Social Neuroscience, 1(3-4), 320-333.  |
| Wood, R., Gallese, V., & Cattaneo, L. (2010). Visuotactile empathy within the primary somatosensory cortex revealed by short-latency afferent inhibition. Neuroscience Letters, 473(1), 28-31. doi: http://dx.doi.org/10.1016/j.neulet.2010.02.012 |
| **Excluded due to outcome (not measuring empathy or ToM) after reviewing full-texts** |
| Baeken, C., Van Schuerbeek, P., De Raedt, R., De Mey, J., Vanderhasselt, M. A., Bossuyt, A., & Luypaert, R. (2011). The effect of one left-sided dorsolateral prefrontal sham-controlled HF-rTMS session on approach and withdrawal related emotional neuronal processes. *Clinical Neurophysiology, 122*(11), 2217-2226. doi: http://dx.doi.org/10.1016/j.clinph.2011.04.009 |
| Brune, M., Scheele, D., Heinisch, C., Tas, C., Wischniewski, J., & Gunturkun, O. (2012). Empathy Moderates the Effect of Repetitive Transcranial Magnetic Stimulation of the Right Dorsolateral Prefrontal Cortex on Costly Punishment. PloS One, 7(9). doi: http://dx.doi.org/10.1371/journal.pone.0044747 |
| Cazzato, V., Mian, E., Serino, A., Mele, S., & Urgesi, C. (2015). Distinct contributions of extrastriate body area and temporoparietal junction in perceiving one's own and others' body. Cognitive Affective & Behavioral Neuroscience, 15(1), 211-228. doi: 10.3758/s13415-014-0312-9 |
| David, N., Jansen, M., Cohen, M. X., Osswald, K., Molnar-Szakacs, I., Newen, A., . . . Paus, T. (2009). Disturbances of self-other distinction after stimulation of the extrastriate body area in the human brain. Social Neuroscience, 4(1), 40-48. doi: 10.1080/17470910801938023 |
| Rossetti, A., Miniussi, C., Maravita, A., & Bolognini, N. (2012). Visual perception of bodily interactions in the primary somatosensory cortex. European Journal of Neuroscience, 36(3), 2317-2323. doi: 10.1111/j.1460-9568.2012.08137.x |

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| **Table S4. Component and overall quality ratings of the reviewed studies** |
| **Study** | **Selection bias** | **Study design** | **Confounders** | **Blinding** | **Data collection method** | **Withdrawals and dropouts** | **Overall** |
| Balconi & Bortolotti, 2012 | + | +++ | +++ | ++ | +++ | +++ | ++ |
| Balconi & Bortolotti, 2013 | + | +++ | +++ | ++ | +++ | +++ | ++ |
| Balconi, Bortolotti, & Gonzaga, 2011 | + | +++ | +++ | ++ | +++ | +++ | ++ |
| Balconi & Canavesio, 2013 | + | +++ | +++ | ++ | +++ | +++ | ++ |
| Balconi & Canavesio, 2016 | + | +++ | +++ | ++ | +++ | +++ | ++ |
| Balconi, Crivelli, & Bortolotti, 2010 | + | +++ | +++ | ++ | +++ | +++ | ++ |
| Bolognini et al., 2013 | + | +++ | +++ | ++ | +++ | +++ | ++ |
| Costa et al., 2008 | + | +++ | +++ | ++ | +++ | +++ | ++ |
| Enticott et al., 2014 | ++ | +++ | +++ | +++ | +++ | +++ | +++ |
| Giardina et al., 2011 | + | +++ | +++ | ++ | +++ | +++ | ++ |
| Hoekert et al., 2010, | + | +++ | +++ | ++ | +++ | +++ | ++ |
| Kalbe et al., 2010 | + | +++ | +++ | ++ | +++ | +++ | ++ |
| Keuken et al., 2011 | + | +++ | +++ | ++ | +++ | +++ | ++ |
| Krause et al., 2012 | + | +++ | +++ | ++ | +++ | +++ | ++ |
| Lev-Ran et al., 2012 | + | +++ | +++ | ++ | +++ | +++ | ++ |
| Michael et al., 2014 | + | +++ | +++ | ++ | + | +++ | + |
| Pobric and Hamilton, 2006 | + | +++ | +++ | ++ | +++ | +++ | ++ |
| Schuwerk et al., 2014 | + | +++ | +++ | ++ | +++ | +++ | ++ |
| Silani et al., 2013 | + | +++ | + | ++ | +++ | +++ | + |
| Uddin et al., 2006 | + | +++ | +++ | ++ | ++ | +++ | ++ |
| Young et al., 2010 | + | +++ | +++ | ++ | +++ | +++ | ++ |
| + = weak, ++ = moderate, +++ = strong |

**Figure S1.** **Study Selection and Search Results**

Removal of 254 duplicates

18 papers (25 trials) included in the meta-analysis

Search results = 506 hits

Embase - 128

Pubmed - 131

PsycInfo - 65

Medline - 59

AMED - 1

Cochrane library - 6

Web of Science - 116

Hand search articles - 2

Grey literature - 0

Total hits = 254 articles were screened after reviewing titles, abstracts, and full-texts

Reasons for exclusion:

174 publications were rejected by title and abstract

20 articles were removed due to their publication type

12 studies did not used rTMS

22 studies did not used behavioural measures

4 studies used irrelevant outcome measures

22 papers subjected to quality assessment systematic review

4 publications were not eligible for meta-analysis due to unavailable data after contacting corresponding authors



Figure S2a. Funnel plot of cognitive ToM trials included in the meta-analysis



Figure S2b. Filled funnel plot of the cognitive ToM trials in the meta-analysis after trim procedure

Empty dots with an outer square represent imputed missing trials.

Abbreviations: s.e., standard error of mean effect size

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Figure S3a. Funnel plot of the affective ToM trials in the meta-analysis



Figure S3b. Filled funnel plot of the affective ToM trials in the meta-analysis after trim procedure

No missing trials were found.

Abbreviations: s.e., standard error of mean effect size