Deschodt, V., Arsac, L. and Rouard, A. (1999) Relative contribution of arms and legs in humans to propulsion in 25-m sprint front-crawl swimming. *European Journal of Applied Physiology and Occupational Physiology* **80,** 192-199. https://doi.org/10.1007/s004210050581

Dos Santos, K., Pereira, G., Papoti, M., Bento, P. and Rodacki, A. (2013) Propulsive force asymmetry during tethered-swimming. *International Journal Of Sports Medicine* **34,** 606-611. https://doi.org/10.1055/s-0032-1327575

Dos Santos, K.B., Bento, P.C.B., Pereira, G., Payton, C. and Rodacki, A.L. (2017) Front crawl swimming performance and bi-lateral force asymmetry during land-based and tethered swimming tests. *Journal of Sports Science & Medicine* **16,** 574. https://pubmed.ncbi.nlm.nih.gov/29238259/

Evershed, J., Burkett, B. and Mellifont, R. (2014) Musculoskeletal screening to detect asymmetry in swimming. *Physical Ttherapy in Sport* **15,** 33-38. https://doi.org/10.1016/j.ptsp.2013.02.002

Ferreira, M.I., Barbosa, T.M., Neiva, H.P., Marta, C.C., Costa, M.J. and Marinho, D.A. (2015) Effect of Gender, Energetics, and Biomechanics on Swimming Masters Performance. *The Journal of Strength & Conditioning Research* **29,** 1948-1955. https://doi.org/10.1519/JSC.0000000000000848

Figueiredo, P., Rouard, A., Vilas-Boas, J.P. and Fernandes, R.J. (2013a) Upper-and lower-limb muscular fatigue during the 200-m front crawl. *Applied Physiology, Nutrition, And Metabolism* **38,** 716-724. https://doi.org/10.1139/apnm-2012-0263

Figueiredo, P., Sanders, R., Gorski, T., Vilas-Boas, J. and Fernandes, R. (2013b) Kinematic and electromyographic changes during 200 m front crawl at race pace. *International Journal Of Sports Medicine* **34,** 49-55. https://doi.org/10.1055/s-0032-1321889

Furuya, S. and Kinoshita, H. (2007) Roles of proximal-to-distal sequential organization of the upper limb segments in striking the keys by expert pianists. *Neuroscience Letters* **421,** 264-269. https://doi.org/10.1016/j.neulet.2007.05.051

Gonjo, T. and Olstad, B.H. (2021) Race analysis in competitive swimming: A narrative review. *International Journal Of Environmental Research And Public Health* **18,** 69. https://doi.org/10.3390/ijerph18010069

Gourgoulis, V., Boli, A., Aggeloussis, N., Toubekis, A., Antoniou, P., Kasimatis, P., Vezos, N., Michalopoulou, M., Kambas, A. and Mavromatis, G. (2014) The effect of leg kick on sprint front crawl swimming. *Journal of Sports Sciences* **32,** 278-289. https://doi.org/10.1080/02640414.2013.823224

Hartwig, T., Naughton, G. and Searl, J. (2006) Motion analyses of adolescent rugby union players: linking training and game demands among under 16 players. *Journal of Science And Medicine In Sport* **9,** 16. https://doi.org/10.1016/j.jsams.2006.12.034

Ikuta, Y., Matsuda, Y., Yamada, Y., Kida, N., Oda, S. and Moritani, T. (2012) Relationship between decreased swimming velocity and muscle activity during 200-m front crawl. *European Journal Of Applied Physiology* **112,** 3417-3429. https://doi.org/10.1007/s00421-012-2321-0

Kellis, E. (1998) Quantification of quadriceps and hamstring antagonist activity. *Sports Medicine* **25,** 37-62. https://doi.org/10.2165/00007256-199825010-00004

Kennedy, P., Brown, P., Chengalur, S.N. and Nelson, R.C. (1990) Analysis of male and female Olympic swimmers in the 100-meter events. *Journal of Applied Biomechanics* **6,** 187-197. https://doi.org/10.1123/ijsb.6.2.187

Kmet, L.M., Cook, L.S. and Lee, R.C. (2004) Standard quality assessment criteria for evaluating primary research papers from a variety of fields. *HTA Initiative **13***. https://doi.org/10.7939/R37M04F16

Knechtle, B., Dalamitros, A.A., Barbosa, T.M., Sousa, C.V., Rosemann, T. and Nikolaidis, P.T. (2020) Sex differences in swimming disciplines—can women outperform men in swimming? *International Journal Of Environmental Research And Public Health* **17,** 3651. https://doi.org/10.3390/ijerph17103651

Kobayashi, K., Takagi, H., Tsubakimoto, S. and Sengoku, Y. (2016). Activation pattern of trunk, thigh and lower leg mucles during underwater dolphin kick in skilled female swimmers. In: *ISBS-Conference Proceedings Archive*. 711-714 https://doi.org/10.5432/jjpehss.15111

Kwok, W.Y., So, B.C.L., Tse, D.H.T. and Ng, S.S.M. (2021) A Systematic Review and Meta-Analysis: Biomechanical Evaluation of the Effectiveness of Strength and Conditioning Training Programs on Front Crawl Swimming Performance. *Journal of Sports Science and Medicine* **20,** 564-585. https://doi.org/10.52082/jssm.2021.564

Lauer, J., Figueiredo, P., Vilas-Boas, J.P., Fernandes, R.J. and Rouard, A.H. (2013) Phase-dependence of elbow muscle coactivation in front crawl swimming. *Journal of Electromyography And Kinesiology* **23,** 820-825. https://doi.org/10.1016/j.jelekin.2013.02.004

Lees, A. (2002) Technique analysis in sports: a critical review. *Journal of Sports Sciences* **20,** 813-828. https://doi.org/10.1080/026404102320675657

Lomax, M. and Castle, S. (2011) Inspiratory muscle fatigue significantly affects breathing frequency, stroke rate, and stroke length during 200-m front-crawl swimming. *The Journal of Strength & Conditioning Research* **25,** 2691-2695. https://doi.org/10.1519/JSC.0b013e318207ead8

Lomax, M., Tasker, L. and Bostanci, O. (2014) Inspiratory muscle fatigue affects latissimus dorsi but not pectoralis major activity during arms only front crawl sprinting. *The Journal of Strength & Conditioning Research* **28,** 2262-2269. https://doi.org/10.1519/JSC.0000000000000379

Marinho, D.A., Barbosa, T.M., Neiva, H.P., Silva, A.J. and Morais, J.E. (2020) Comparison of the start, turn and finish performance of elite swimmers in 100 m and 200 m races. *Journal of Sports Science & Medicine* **19,** 397. https://pubmed.ncbi.nlm.nih.gov/32390734/

Martens, J., Daly, D., Deschamps, K., Fernandes, R.J.P. and Staes, F. (2015a) Intra-individual variability of surface electromyography in front crawl swimming. *PlosOne* **10,** e0144998. https://doi.org/10.1371/journal.pone.0144998

Martens, J., Daly, D., Deschamps, K., Staes, F. and Fernandes, R.J. (2016) Inter-individual variability and pattern recognition of surface electromyography in front crawl swimming. *Journal of Electromyography and Kinesiology* **31,** 14-21. https://doi.org/10.1016/j.jelekin.2016.08.016

Martens, J., Figueiredo, P. and Daly, D. (2015b) Electromyography in the four competitive swimming strokes: A systematic review. *Journal of electromyography And Kinesiology* **25,** 273-291. https://doi.org/10.1016/j.jelekin.2014.12.003

Matsuda, Y., Hirano, M., Yamada, Y., Ikuta, Y., Nomura, T., Tanaka, H. and Oda, S. (2016) Lower muscle co-contraction in flutter kicking for competitive swimmers. *Human Movement Science* **45,** 40-52. https://doi.org/10.1016/j.humov.2015.11.001

Mooney, R., Corley, G., Godfrey, A., Osborough, C., Newell, J., Quinlan, L.R. and ÓLaighin, G. (2016) Analysis of swimming performance: perceptions and practices of US-based swimming coaches. *Journal of Sports Sciences* **34,** 997-1005. https://doi.org/10.1080/02640414.2015.1085074

Morais, J.E., Barbosa, T.M., Forte, P., Pinto, J.N. and Marinho, D.A. (2021a) Assessment of the inter-lap stability and relationship between the race time and start, clean swim, turn and finish variables in elite male junior swimmers' 200 m freestyle. *Sports Biomechanics* 1-14. https://doi.org/10.1080/14763141.2021.1952298

Morais, J.E., Barbosa, T.M., Forte, P., Silva, A.J. and Marinho, D.A. (2021b) Young Swimmers' Anthropometrics, Biomechanics, Energetics, and Efficiency as Underlying Performance Factors: A Systematic Narrative Review. *Frontiers in Physiology* 1485. https://doi.org/10.3389/fphys.2021.691919

Morais, J.E., Marinho, D.A., Arellano, R. and Barbosa, T.M. (2019) Start and turn performances of elite sprinters at the 2016 European Championships in swimming. *Sports Biomechanics* **18,** 100-114. https://doi.org/10.1080/14763141.2018.1435713

Morais, J.E., Silva, A.J., Marinho, D.A., Lopes, V.P. and Barbosa, T.M. (2017) Determinant factors of long-term performance development in young swimmers. *International Journal Of Sports Physiology And Performance* **12,** 198-205. https://doi.org/10.1123/ijspp.2015-0420

Morouço, P.G., Marinho, D.A., Fernandes, R.J. and Marques, M.C. (2015a) Quantification of upper limb kinetic asymmetries in front crawl swimming. *Human Movement Science* **40,** 185-192. https://doi.org/10.1016/j.humov.2014.12.012

Morouço, P.G., Marinho, D.A., Izquierdo, M., Neiva, H. and Marques, M.C. (2015b) Relative contribution of arms and legs in 30 s fully tethered front crawl swimming. *BioMed research International* **2015**. https://doi.org/10.1155/2015/563206

Morris, K.S., Jenkins, D.G., Osborne, M.A., Rynne, S.B., Shephard, M.E.

and Skinner, T.L. (2019) The role of the upper and lower limbs in front crawl swimming: the thoughts and practices of expert high-performance swimming coaches. *International Journal of Sports Science & Coaching* **14,** 629-638. https://doi.org/10.1177/1747954119866358

Naemi, R., Easson, W.J. and Sanders, R.H. (2010) Hydrodynamic glide efficiency in swimming. *Journal of Science And Medicine In Sport* **13,** 444-451. https://doi.org/10.1016/j.jsams.2009.04.009

Nicol, E., Ball, K. and Tor, E. (2019) The biomechanics of freestyle and butterfly turn technique in elite swimmers. *Sports Biomechanics*. https://doi.org/10.1080/14763141.2018.1561930

Olstad, B.H., Zinner, C., Cabri, J. and Kjendlie, P.-L. (2014) Surface electromyographic measurements on land prior to and after 90 min of submersion (swimming) are highly reliable. *Journal of Electromyography and Kinesiology* **24,** 698-703. https://doi.org/10.1016/j.jelekin.2014.06.006

Pedersen, T. and Kjendlie, P.-L. (2006) The effect of the breathing action on velocity in front crawl sprinting. *Portuguese Journal of Sport Science* **6,** 75-77.

Pereira, S.M., Ruschel, C., Hubert, M., Machado, L., Roesler, H., Fernandes, R.J. and Vilas-Boas, J.P. (2015) Kinematic, kinetic and EMG analysis of four front crawl flip turn techniques. *Journal of Sports Sciences* **33,** 2006-2015. https://doi.org/10.1080/02640414.2015.1026374

Pink, M., Perry, J., Browne, A., Scovazzo, M.L. and Kerrigan, J. (1991) The normal shoulder during freestyle swimming: an electromyographic and cinematographic analysis of twelve muscles. *The American Journal of Sports Medicine* **19,** 569-576. https://doi.org/10.1177/036354659101900603

Pino, J., Martinez-Santos, R., Moreno, M.I. and Padilla, C. (2007) Automatic analysis of football games using GPS on real time. *Journal of Sports Science and Medicine* **6(Suppl. 10)** , 9. Available from URL: https://www.jssm.org/suppls/10/Suppl.10.p6-11.pdf

Psycharakis, S.G. and McCabe, C. (2011) Shoulder and hip roll differences between breathing and non-breathing conditions in front crawl swimming. *Journal of Biomechanics* **44,** 1752-1756. https://doi.org/10.1016/j.jbiomech.2011.04.004

Puce, L., Pallecchi, I., Marinelli, L., Mori, L., Bove, M., Diotti, D., Ruggeri, P., Faelli, E., Cotellessa, F. and Trompetto, C. (2021) Surface Electromyography Spectral Parameters for the Study of Muscle Fatigue in Swimming. *Frontiers in Sports and Active Living* **3**, 2021-February-19. https://doi.org/10.3389/fspor.2021.644765

Puel, F., Morlier, J., Avalos, M., Mesnard, M., Cid, M. and Hellard, P. (2012) 3D kinematic and dynamic analysis of the front crawl tumble turn in elite male swimmers. *Journal of Biomechanics* **45,** 510-515. https://doi.org/10.1016/j.jbiomech.2011.11.043

Randers, M.B., Mujika, I., Hewitt, A., Santisteban, J., Bischoff, R., Solano, R., Zubillaga, A., Peltola, E., Krustrup, P. and Mohr, M. (2010) Application of four different football match analysis systems: A comparative study. *Journal of Sports Sciences* **28,** 171-182. https://doi.org/10.1080/02640410903428525

Rouard, A. and Clarys, J. (1995) Cocontraction in the elbow and shoulder muscles during rapid cyclic movements in an aquatic environment. *Journal of Electromyography And Kinesiology* **5,** 177-183. https://doi.org/10.1016/1050-6411(95)00008-N

Ruiz-Navarro, J.J., Cuenca-Fernández, F., Sanders, R. and Arellano, R. (2022) The determinant factors of undulatory underwater swimming performance: A systematic review. *Journal of sports Sciences* 1-12. https://doi.org/10.1080/02640414.2022.2061259

Rüst, C.A., Rosemann, T. and Knechtle, B. (2014) Sex difference in age and performance in elite Swiss freestyle swimmers competing from 50 m to 1,500 m. *Springerplus* **3,** 1-10. https://doi.org/10.1186/2193-1801-3-228

Sanders, R., Thow, J., Alcock, A., Fairweather, M., Riach, I. and Mather, F. (2012) How can asymmetries in swimming be identified and measured? *Journal of Swimming Research* **19**.

Seifert, L., Chollet, D. and Allard, P. (2005) Arm coordination symmetry and breathing effect in front crawl. *Human Movement Science* **24,** 234-256. https://doi.org/10.1016/j.humov.2005.05.003

Seifert, L., Chehensse, A., Tourny-Chollet, C., Lemaitre, F. and Chollet, D. (2008) Effect of breathing pattern on arm coordination symmetry in front crawl. *The Journal of Strength & Conditioning Research* **22,** 1670-1676. https://doi.org/10.1519/JSC.0b013e318182029d

Solomonow, M., Baratta, R., Zhou, B. and d'Ambrosia, R. (1988) Electromyogram coactivation patterns of the elbow antagonist muscles during slow isokinetic movement. *Experimental Neurology* **100,** 470-477. https://doi.org/10.1016/0014-4886(88)90032-5

Stirn, I., Jarm, T., Kapus, V. and Strojnik, V. (2011) Evaluation of muscle fatigue during 100-m front crawl. *European Journal of Applied Physiology* **111,** 101-113. https://doi.org/10.1007/s00421-010-1624-2

Taborri, J., Keogh, J., Kos, A., Santuz, A., Umek, A., Urbanczyk, C., van der Kruk, E. and Rossi, S. (2020) Sport Biomechanics Applications Using Inertial, Force, and EMG Sensors: A Literature Overview. *Applied Bionics and Biomechanics* **2020,** 2041549. https://doi.org/10.1155/2020/2041549

Taylor, J.L., Todd, G. and Gandevia, S.C. (2006) Evidence for a supraspinal contribution to human muscle fatigue. *Clinical and experimental Pharmacology And Physiology* **33,** 400-405. https://doi.org/10.1111/j.1440-1681.2006.04363.x

Thompson, I., Warner, M., Hudson, D., Banks, J. and Logan, O. (2022) Coaching practices to develop underwater fly kick performance in swimming training. *International Journal of Sports Science & Coaching* 17479541221101598.

Türker, H. and Sze, H. (2013) Surface electromyography in sports and exercise. *Electrodiagnosis in new Frontiers Of Clinical Research* 175-194. https://doi.org/10.5772/56167

Veiga, S. and Roig, A. (2016) Underwater and surface strategies of 200 m world level swimmers. *Journal of sports sciences* **34,** 766-771. https://doi.org/10.1080/02640414.2015.1069382

Veiga, S., Roig, A. and Gómez-Ruano, M.A. (2016) Do faster swimmers spend longer underwater than slower swimmers at World Championships? *European Journal Of Sport Science* **16,** 919-926. https://doi.org/10.1080/17461391.2016.1153727

Vinod, A.P. and Da, C.Y. (2013). An integrated surface EMG data acquisition system for sports medicine applications. In: *2013 7th International Symposium on Medical Information and Communication Technology (ISMICT)*, IEEE, pp. 98-102. https://doi.org/10.1109/ISMICT.2013.6521708

Vlantes, T.G. and Readdy, T. (2017) Using Microsensor Technology to Quantify Match Demands in Collegiate Women's Volleyball. *The Journal of Strength & Conditioning Research* **31,** 3266-3278. https://doi.org/10.1519/JSC.0000000000002208

Winter, D.A. (2009) *Biomechanics and motor control of human movement*. John Wiley & Sons. https://doi.org/10.1002/9780470549148

Yamakawa, K.K., Shimojo, H., Takagi, H., Tsubakimoto, S. and Sengoku, Y. (2017) Effect of increased kick frequency on propelling efficiency and muscular co-activation during underwater dolphin kick. *Human movement science* **54,** 276-286. https://doi.org/10.1016/j.humov.2017.06.002

Key points

- Biased investigations of upper limbs' muscles activity due to the important role in FC swim.
- More experiments should be conducted to evaluate muscle activity during starts and turns.
- Insufficient information about the muscle activity of leg and trunk muscles during FC swim.
- More exploration about the roles or contribution of muscle co-activation on swimming performance is highly recommended.

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