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Twenty Seconds of Finger Tapping: A Borderland for Contralateral Transfer of Repeated Bout Rate Enhancement

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A R T I C L E I N F O

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A B S T R A C T

Background: To test the hypothesis that a 20-s bout of unilateral index finger tapping, followed by 10 min rest, increases the freely chosen tapping rate performed by the contralateral index finger, in a second 20-s bout.

Methods: Twenty healthy adults performed tapping with the index finger on one hand followed by a 10 min rest period and tapping with the other index finger. Tapping was performed at freely chosen rate. Testing was performed with dominant hand first as well as in the opposite order.

Results: Freely chosen tapping rates from the first bouts were 161.6±94.2 and 162.8±80.3 taps per min for the dominant and non-dominant hand, respectively (p=0.903; R=0.89, p<0.001). When bout one was performed with the non-dominant hand, the rate increased by 15.0%±22.3% in about two (p=0.008). In the opposite order, the rate remained similar (+4.8%±17.9%, but p=0.655).

Conclusion: Based on the present, as well as previously published results, the interpretation is that 20 s of initial index finger tapping appears to constitute a borderland for elicitation of subsequent contralateral excitation of freely chosen tapping rate.

1. Introduction

Control and behavior of rhythmic, stereotyped, and automated motor activities are relevant topics to investigate. One reason is academic pursuit of knowledge, which can provide an improved understanding of human motor control. Besides, application of new research-based knowledge is important. Merely as a couple of examples, neurorehabilitation as well as integration of human and machine, within the exoskeleton field, have been suggested to be strengthened by as much understanding as possible of aspects of motor output rhythmicity (Gad et al., 2017; Hansen, 2021; Zhu et al., 2021).

Tapping with an index finger is a widely applied motor task for investigations of voluntary, stereotyped, rhythmic movements in healthy individuals (Hammond & Gunasekera, 2008; Wing & Kristofferson, 1973; Zentgraf et al., 2009) as well as in patients (Pitcher et al., 2002; Roche et al., 2016; Teo et al., 2013). Such a simple type of tapping consists of repeated alternating flexion and extension of the metacarpal phalangeal joint that primarily is performed by repeated alternating activation of the extensor digitorum muscle and the flexor digitorum profundus muscle. Tapping can be generated with a high degree of volitional effort – for example if a preset target rate has to be achieved exactly. However, we are interested in finger tapping performed at a freely chosen rate at which the conscious attention on the task is considered low whereas a high degree of automation of the motor output rhythm is considered to occur.

Repeated bout rate enhancement is a behavioral phenomenon (Hansen et al., 2015; Mora-Jensen et al., 2017). It comprises an about 6% increase of the freely chosen index finger tapping rate in the second of two consecutive 3-min tapping bouts, which are separated by 10 min rest. In other words, it suggests an excitement of the neural rhythm generating elements, which produces the submaximal and stereotyped rate during freely chosen tapping. It has been suggested that the repeated bout rate enhancement might be a result of a net excitation of spinal neural networks involved in the generation of the tapping rate (Hansen et al., 2015). Neuromodulation caused by neurotransmitters might be responsible for that (Bucher et al., 2015; Frigon, 2017; Majczynski et al., 2020; Sanchez & Kirk, 2000). The freely chosen tapping rate has been described as an attractor in a dynamic complex self-organized system, according to dynamic systems theory (Hansen, 2021). Further, it has been considered that factors such as state of excitation, training adaptation, and learning, merely to mention some, may be able to affect the behavior of the system and, thus, the output of the system (Hansen, 2021).

Recently, it was reported that tapping with the index finger on one hand elicited an about 8%-14% rate enhancement during a second tapping bout performed with the other hand, following 10 min of rest (Hansen et al., 2020). This observation was denoted contralateral transfer of the phenomenon of repeated bout rate enhancement. As a potential mechanism, it was suggested that perhaps neuromodulators, released during neural activity in the first bout, excited key spinal neural rhythm generating elements, which mediated the tapping rate of the contralateral index finger (Hansen et al., 2020). The possibility that such a neuromodulation can occur has been discussed by others (Cropper et al., 2017; Gad et al., 2017; Perrier & Cotel, 2015). Increased bilateral corticospinal excitability following unilateral training has also been reported (Carroll et al., 2008). And for completeness, since stereotyped rhythmic motor output is considered to be generated in an interrelationship between spinal neural networks, supraspinal input, and sensory feedback, it should be noted that it is difficult to precisely locate where modulations occur.

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In the study by Hansen et al. (2020), 3-min tapping bouts were applied. As a part of a further exploration, it is of interest to investigate whether a shorter priming time can elicit the same phenomenon of rate enhancement. Consequently, the purpose of the present study was to test the following hypothesis: A 20-s bout of unilateral index finger tapping, followed by 10 min rest, increases the freely chosen tapping rate performed by the contralateral index finger, in a second 20-s bout. The choice of 20-s tapping bouts in the present study was inspired by the fact that a recent study showed that 20 s of tapping was enough to elicit repeated bout rate enhancement - for tapping with the same index finger, it should be noted (Emanuelsen et al., 2021).

2. Materials and Methods

2.1. Subjects

Twenty (11 men, 9 women) healthy individuals (29 ± 10 years, 1.73 ± 0.10 m, 72.4 ± 11.9 kg) were recruited for the study. Nineteen were right-handed, while one was left-handed, according to their own statement. They were carefully informed about the procedures of the study and the overall aim ("to enlarge our knowledge about behavior and control of rhythmic movement") but at the same time kept naive to the specific purpose. The latter served to avoid any particular conscious control of the tapping. None of the participants had any history of neural or musculoskeletal diseases. In addition, they did not perform rhythmic movements with their fingers such as during playing an instrument or playing computer games on a daily basis. One participant stated that he was left-handed. The rest stated that they were right-handed. Participants were instructed not to consume coffee during the last 3 hr before testing. In addition, they were instructed not to consume alcohol or euphoriant substances during the last 24 hr before testing. Written informed consent was obtained from the participants. The study conformed to the standards set by the Declaration of Helsinki and the procedures by The North Denmark Region Committee on Health Research Ethics.

2.2. Apparatus and task

Tapping was performed on an iPhone XS (Apple Inc., Cupertino, CA, USA) installed with the Tap Tap Counter app (Sonia Aslam, IN Business Solutions). The number of taps in a bout was noted and subsequently timed by three, to get the tapping rate in taps per min.

2.3. Procedures

For the present study, a repeated measures crossover design was applied. To begin with, participants were randomly assigned into two groups. Group 1 performed unilateral index finger tapping with the dominant hand first (Bout 1) and subsequently (Bout 2) with the non-dominant hand in the first test session. In a second test session, this part of the participants reversed the order of tapping. Group 2 performed index finger tapping with the non-dominant hand first (Bout 1) and subsequently (Bout 2) with the dominant hand in the first test session. In a second test session, this part of the participants also reversed the order of tapping. The first and the second test session were separated by a minimum of 21 days. The justification for the 21 days of separation between test sessions is that fourteen days (Hansen & Ohnstad, 2008) and sixteen days (Hansen et al., 2015) previously have been reported to result in a stable baseline of the freely chosen tapping rate. For comparison, another study indicated that only seven days of separation between test sessions can result in an increase of the freely chosen tapping rate from session to session (Sardroodian et al., 2016). Participants completed the test sessions at approximately the same time of day (i.e., with a maximal difference of 2 h). The reason was to prevent any influence of circadian rhythm on finger tapping rate (Moussay et al., 2002). Figure 1 illustrates the experimental design of the present study.

At the attendance, the participant was informed about the procedure. Instruction and physical demonstration of index finger tapping was performed by the test leader. No warm up or familiarization was performed by the participant. The participant was seated in an adjustable chair and encouraged to find a comfortable position where index finger tapping could be performed. This setup can be seen in figure 2 in the paper by Sardroodian et al. (2016). Before the first tapping bout started, it was stressed that tapping was neither supposed to be performed as fast as possible nor with as high a force as possible. Further, that there was no correct or incorrect tapping rate. Rather, the participant should "tap in a relaxed and natural way at a freely chosen rate and apply a preferred rhythm". In order to test that the participant had understood the task, the participant was finally asked to explain the task to the test leader.

The first tapping bout in a test session consisted of 20 s of unilateral index finger tapping at a freely chosen tapping rate. Hereafter, a 10-min rest period followed. Subsequently, a second 20-s tapping bout of freely chosen unilateral index finger tapping was performed with the finger of the other hand.

2.4. Data analysis

The Shapiro-Wilks test was performed in SPSS 27.0 (SPSS Inc., Chicago, IL, USA) to evaluate whether the data were different from a normal distribution. That was not the case ($p > 0.216$). The student's paired two-tailed t-test was applied for comparisons and a Pearson product-moment correlation coefficient was calculated. These latter tests were performed in Excel 2016 (Microsoft Corporation, Bellevue, WA, USA). For interpretation of the correlation coefficient, R, < 0.25 was considered weak, 0.25 to 0.50 was considered moderate, 0.51 to 0.75 was considered fair, and > 0.75 was considered high (Berg & Latin, 2008). Data are presented as mean ± standard deviation (SD) unless otherwise indicated. The significance level was set at $p < 0.050$.

3. Results

With respect to the time of day, there was 39 ± 36 min difference between the first and the second test session.

The freely chosen tapping rate amounted to 161.62 ± 94.2 taps per min and 162.8 ± 80.3 taps per min for the index finger of the dominant and the non-dominant hand, respectively ($p = 0.903$). For calculation of these values, tapping rates from the first tapping bouts, i.e., at two different days, were applied. Besides, there was a high correlation ($R = 0.89$, $p < 0.001$) between the tapping rates recorded for the dominant and the non-dominant hand (Figure 2).

When the first tapping bout was performed with the index finger of the non-dominant hand and the second bout was performed with the index finger of the dominant hand, the tapping rate increased by 15.0% ± 22.3% in the second bout ($p = 0.008$). For comparison, when the first tapping bout was performed with the index finger of the dominant hand and the second bout was performed with the index finger of the non-dominant hand, the tapping rate remained similar (+ 4.8% ± 17.9%, but non-significant: $p = 0.655$). For absolute values, the reader is referred to figure 3.

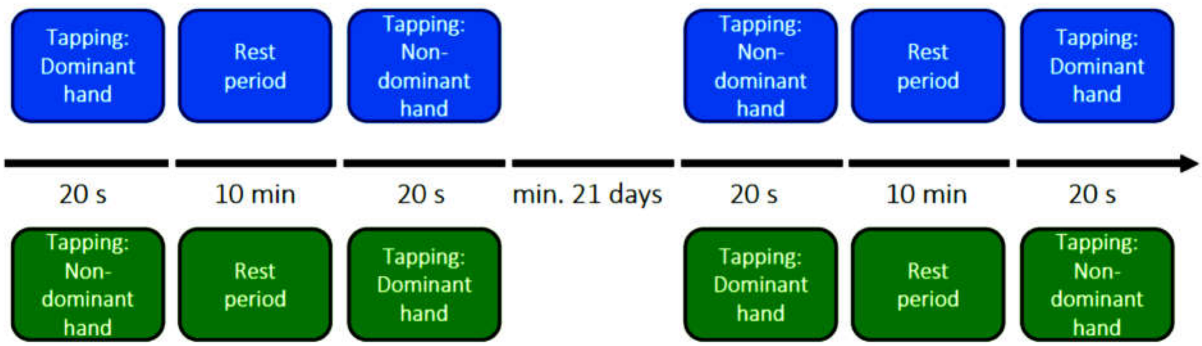

Figure 1. An illustration of the design of the present study.

Note: Half of the participants performed a bout with the dominant hand first, followed by a rest period and a bout with the non-dominant hand. Further, they repeated the bouts in the opposite order after a 21-day period (blue boxes). The other half of the participants completed the bouts in the opposite order (green boxes), to avoid a systematic order effect. At the end, all participants had performed the same tapping bouts. However, not in the same order.

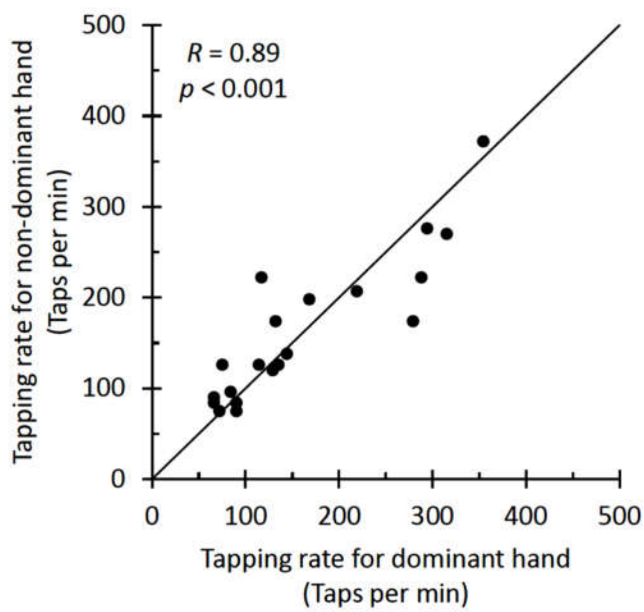

Figure 2. Freely chosen unilateral index finger tapping rate for the index finger of the dominant hand as a function of rate recorded for the index finger of the non-dominant hand (recorded another day).

All data are from the first tapping bout in a test session. A line of identity is included. Each data point represents a single participant. n = 20.

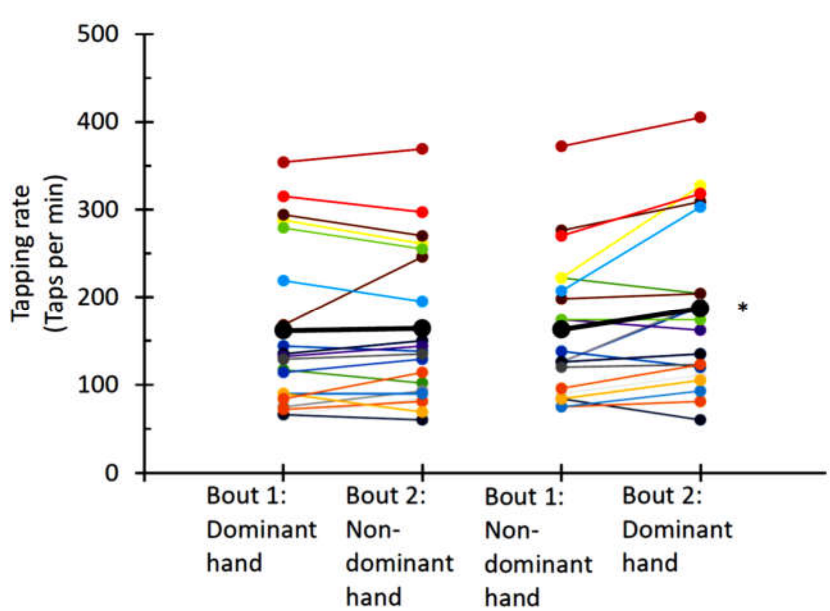

Figure 3. Freely chosen unilateral index finger tapping rates.

Note: Black data points represent mean values across the participants. Other colors represent individual values. Each single participant is represented by a distinct color. SD-values are omitted for clarity but can be found in the results section. n = 20. *Different from about 1 in the same test session, performed with the non-dominant hand (p = 0.008).

4. Discussion and Conclusion

Analysis of motor behavior may be used to increase our understanding of the organization and function of the nervous system (Goulding, 2009). Accordingly, the present study applied an operational approach that links experimental observations to theory, as suggested by others (Kelso & Schöner, 1988). The same kind of approach has been carried out previously (Jeka et al., 1993; Nielsen et al., 2022; Sakamoto et al., 2007; Sardroodian et al., 2015).

The present basic freely chosen tapping rate, of about 162 taps per min, for the entire group of participants, is similar to some previously published values from our laboratory (163 taps per min (Mora-Jensen et al., 2017) and 167 taps per min (Hansen et al., 2020). At the same time, the present value is somewhat lower than other published values (202 taps per min (Hansen et al., 2015) and 245 taps per min (Hansen & Ohnstad, 2008). Participants were not the same in all these mentioned studies. Still, characteristics of the participants and the data collection methods were similar. Therefore, random between-sample differences is probably the reason for the differences.

The present study showed a high correlation (R = 0.89) between the freely chosen index finger tapping rate performed by the index finger of the dominant hand in the first bout and the corresponding tapping rate performed by the index finger of the non-dominant hand (also measured in the first bout, but on another day). This finding corresponds with a similar previous finding of an R-value of 0.86 (Hansen et al., 2020).

Similar previous findings of high correlations of unilateral freely chosen movement rates performed by the two legs, separately, during rhythmic leg exercise tasks (Stang et al., 2016) caused Stang et al. (2016) to suggest that involved spinal neural networks involved in the rhythm generation perhaps shares a common rate generator. Or alternatively, that separate rate generators for each limb are attuned via interneuronal connections.

The novel finding from the present study was that a single 20-s bout of freely chosen tapping with the index finger of the non-dominant hand enhanced the freely chosen tapping rate performed in a second tapping bout with the index finger of the dominant hand by about 15%. In addition, that tapping in the opposite order did not elicit a similar rate enhancement.

The physiological mechanisms underlying the observed acute contralateral transfer can obviously only be speculated upon because of the behavioral character of the present study. It is possible that the present repeated bout rate enhancement effect should be considered a kind of repetition priming, as described previously (Cropper et al., 2017; Siniscalchi et al., 2016). The present findings may also be interpreted to support the working hypothesis proposed by Stang et al. (2016) that involved spinal neural networks either share a common rate generator or that separated rate generators are attuned via interneurons. Further, it is possible that neuromodulators released during neural activity in the first bout, performed with the index finger of the non-dominant hand, excited the rhythm generating neural elements responsible for the tapping rate of the contralateral index finger. And that this caused the generation of a higher tapping rate in the second bout, performed with the dominant hand. The possibility that spinal neural network-mediated rhythmicity is excited by released neuromodulators has been discussed by others (Bucher et al., 2015; Cropper et al., 2017; Gad et al., 2017; Perrier & Cotel, 2015).

Finally, it remains to be reflected upon why no contralateral transfer of the phenomenon of repeated bout rate enhancement occurred from the dominant hand to the non-dominant hand. A suggestion is that unilateral tapping-like activities with the index finger of the dominant hand are more frequently performed than with the finger of the non-dominant hand. If this assumption is correct, it might affect the involved neural pathways, responsible for the contralateral transfer, to be less susceptible to a net excitation. Though, this is merely a suggestion made to motivate to future studies.

The present findings are not only of academic interest. They may also have relevant clinical implications for movement rehabilitation. Thus, the present study supports the notion that it is possible to train an unaffected limb of a patient in order to increase the excitability of the part of the nervous system involved in generation of movement of a contralateral affected limb. Such a strategy could be considered a supplement to strategies of electrical and pharmacological stimulation, as well as passive movement of affected limbs, which were mentioned in a previously published review (Hofstoetter et al., 2017). However, the present findings also suggest that more than 20 s of activity might be required, when targeting the motor output of stereotyped rhythmic movements. Interlimb transfer of performance of unilateral index finger movement has been reported previously. Thus, Carroll et al. (2008) had participants perform practice trials of ballistic abduction movements of the right index finger. The purpose of their training was to improve the peak acceleration of the movement. The researchers reported that training improved performance by 140% in the right hand and by 82% in the untrained left hand (Carroll et al., 2008). In addition, bilateral corticospinal excitability was increased following the unilateral training. A control group was included in the study, for comparison, and that group showed no changes (Carroll et al., 2008). Though, it should be noted that the tapping task applied in the present study can be characterized as being submaximal, simple, stereotyped, and performed at a freely chosen rate. Furthermore, the present study, like our closely related study (Hansen et al., 2020), focused on acute transfer effects rather than on effects of long-term training. Thus, aspects such as maximal performance, long term training, and learning may be of minor relevance for the present study.

The present study tested the hypothesis that a 20-s initial bout of unilateral index finger tapping, followed by 10 min rest, increases the freely chosen tapping rate performed by the contralateral index finger, in a second 20-s bout of tapping. With an about 15% rate enhancement, the hypothesis was confirmed in the case where the first bout was performed with the index finger of the non-dominant hand. For comparison, no such rate enhancement was observed when the first bout was performed with the index finger of the dominant hand. Based on the present results, and previously reported observations obtained by applying 3-min tapping bouts, it is suggested that 20 s of tapping appears to constitute a borderland for elicitation of contralateral transfer of the phenomenon of repeated bout rate enhancement in unilateral index finger tapping.

Conflict of interests

The authors have no conflict of interests.

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References

Berg, K. E., & Latin, R. W. (2008). Essentials of research methods in health, physical education, exercise science, and recreation (3 ed.). Wolters Kluwer.

Bucher, D., Haspel, G., Golowasch, J., & Nadim, F. (2015). Central pattern generators. In: eLS. John Wiley & Sons, Ltd: Chichester. https://doi.org/10.1002/9780470015902.a0000032.pub2

Carroll, T. J., Lee, M., Hsu, M., & Sayde, J. (2008). Unilateral practice of a ballistic movement causes bilateral increases in performance and corticospinal excitability. J Appl Physiol, 104, 1656-1664. https://doi.org/10.1152/japplphysiol.01351.2007

Cropper, E. C., Jing, J., Perkins, M. H., & Weiss, K. R. (2017). Use of the Aplysia feeding network to study repetition priming of an episodic behavior. J Neurophysiol, 118, 1861-1870. https://doi.org/10.1152/jn.00373.2017

Emanuelsen, A., Voigt, M., Madeleine, P., & Hansen, E. A. (2021). Effect of tapping bout duration during freely chosen and passive finger tapping on rate enhancement. J Mot Behav, 53, 351-363. https://doi.org/10.1080/00222895.2020.1779021

Frigon, A. (2017). The neural control of interlimb coordination during mammalian locomotion. J Neurophysiol, 117, 2224-2241. https://doi.org/10.1152/jn.00978.2016

Gad, P., Gerasimenko, Y., Zdunowski, S., Turner, A., Sayenko, D., Lu, D. C., & Edgerton, V. R. (2017). Weight Bearing Overground Stepping in an Exoskeleton with Non-invasive Spinal Cord Neuromodulation after Motor Complete Paraplegia. Front Neurosci, 11:333. https://doi.org/10.3389/fnins.2017.00333

Goulding, M. (2009). Circuits controlling vertebrate locomotion: moving in a new direction. Nat Rev Neurosci, 10, 507-518. https://doi.org/nrn2608

Hammond, G., & Gunasekera, S. (2008). Production of successive force impulses by the left and right hands. J Mot Behav, 40, 409-416. https://doi.org/63078PQ8T7K42TKW

Hansen, E. A. (2021). Unprompted Alteration of Freely Chosen Movement Rate During Stereotyped Rhythmic Movement: Examples and Review. Motor Control, 25, 385-402. https://doi.org/10.1123/mc.2020-0049

Hansen, E. A., Bak, S., Knudsen, L., Seiferheld, B. E., Stevenson, A. J. T., & Emanuelsen, A. (2020). Contralateral Transfer of the Phenomenon of Repeated Bout Rate Enhancement in Unilateral Index Finger Tapping. J Mot Behav, 52, 89-96. https://doi.org/10.1080/00222895.2019.1592101

Hansen, E. A., Ebbesen, B. D., Dalsgaard, A., Mora-Jensen, M. H., & Rasmussen, J. (2015). Freely chosen index finger tapping frequency is increased in repeated bouts of tapping. J Mot Behav, 47, 490-496. DOI: 10.1080/00222895.2015.1015675

Hansen, E. A., & Ohnstad, A. E. (2008). Evidence for freely chosen pedalling rate during submaximal cycling to be a robust innate voluntary motor rhythm. Exp Brain Res, 186, 365-373. DOI 10.1007/s00221-007-1240-5

Hofstoetter, U. S., Knikou, M., Guertin, P. A., & Minassian, K. (2017). Probing the Human Spinal Locomotor Circuits by Phasic Step-Induced Feedback and by Tonic Electrical and Pharmacological Neuromodulation. Curr Pharm Des, 23, 1805-1820. https://doi.org/10.2174/1381612822666161214144655

Jeka, J. J., Kelso, J. A. S., & Kiemel, T. (1993). Spontaneous transitions and symmetry: Pattern dynamics in human four-limb coordination. Hum Mov Sci, 12, 627-651.

Kelso, J. A. S., & Schöner, G. (1988). Self-organization of coordinative movement patterns. Hum Mov Sci, 7, 27-46.

Majczynski, H., Cabaj, A. M., Jordan, L. M., & Slawinska, U. (2020). Contribution of 5-HT2 Receptors to the Control of the Spinal Locomotor System in Intact Rats. Front Neural Circuits, 14:14. https://doi.org/10.3389/fncir.2020.00014

Mora-Jensen, M. H., Madeleine, P., & Hansen, E. A. (2017). Vertical finger displacement is reduced in index finger tapping during repeated bout rate enhancement. Motor Control, 21, 457-467. doi: 10.1123/mc.2016-0037

Moussay, S., Dosseville, F., Gauthier, A., Larue, J., Sesboüe, B., & Davenne, D. (2002). Circadian rhythms during cycling exercise and finger-tapping task. Chronobiol Int, 19, 1137-1149. http://www.ncbi.nlm.nih.gov/pubmed/12511031

Nielsen, B. M., Fjordside, C., Jensen, N. B., & Hansen, E. A. (2022). History dependence of freely chosen index finger tapping rhythmicity. IJMCL, 4, 9-18.

Perrier, J. F., & Cotel, F. (2015). Serotonergic modulation of spinal motor control. Curr Opin Neurobiol, 33, 1-7. https://doi.org/10.1016/j.conb.2014.12.008

Pitcher, T. M., Piek, J. P., & Barrett, N. C. (2002). Timing and force control in boys with attention deficit hyperactivity disorder: subtype differences and the effect of comorbid developmental coordination disorder. Hum Mov Sci, 21, 919-945. https://www.ncbi.nlm.nih.gov/pubmed/12620726

Roche, R., Viswanathan, P., Clark, J. E., & Whitall, J. (2016). Children with developmental coordination disorder (DCD) can adapt to perceptible and subliminal rhythm changes but are more variable. Hum Mov Sci, 50, 19-29. https://doi.org/10.1016/j.humov.2016.09.003

Sakamoto, M., Tazoe, T., Nakajima, T., Endoh, T., Shiozawa, S., & Komiyama, T. (2007). Voluntary changes in leg cadence modulate arm cadence during simultaneous arm and leg cycling. Exp Brain Res, 176, 188-192. http://www.ncbi.nlm.nih.gov/pubmed/17061091

Sanchez, J. A. D., & Kirk, M. D. (2000). Short-term synaptic enhancement modulates ingestion motor programs of aplysia. J Neurosci, 20, RC85. https://www.ncbi.nlm.nih.gov/pubmed/10875940

Sardroodian, M., Madeleine, P., Mora-Jensen, M. H., & Hansen, E. A. (2016). Characteristics of Finger Tapping Are Not Affected by Heavy Strength Training. J Mot Behav, 48, 256-263. https://doi.org/10.1080/00222895.2015.1089832

Sardroodian, M., Madeleine, P., Voigt, M., & Hansen, E. A. (2015). Freely chosen stride frequencies during walking and running are not correlated with freely chosen pedalling frequency and are insensitive to strength training. Gait Posture, 42, 60-64. doi: 10.1016/j.gaitpost.2015.04.003

Siniscalchi, M. J., Cropper, E. C., Jing, J., & Weiss, K. R. (2016). Repetition priming of motor activity mediated by a central pattern generator: the importance of extrinsic vs. intrinsic program initiators. J Neurophysiol, 116, 1821-1830. https://doi.org/10.1152/jn.00365.2016

Stang, J., Wiig, H., Hermansen, M., & Hansen, E. A. (2016). Voluntary movement frequencies in submaximal one- and two-legged Knee extension exercise and pedaling. Front Hum Neurosci, 10:36. doi: 10.3389/fnhum.2016.00036

Teo, W. P., Rodrigues, J. P., Mastaglia, F. L., & Thickbroom, G. W. (2013). Comparing kinematic changes between a finger-tapping task and unconstrained finger flexion-extension task in patients with Parkinson's disease. Exp Brain Res, 227, 323-331. https://doi.org/10.1007/s00221-013-3491-7

Wing, A. M., & Kristofferson, A. B. (1973). The timing of interresponse intervals. Percept Psychophys, 13, 455-460.

Zentgraf, K., Lorey, B., Bischoff, M., Zimmermann, K., Stark, R., & Munzert, J. (2009). Neural correlates of attentional focusing during finger movements: A fMRI study. J Mot Behav, 41, 535-541. https://doi.org/E320751124N88812

Zhu, Y., Weston, E. B., Mehta, R. K., & Marras, W. S. (2021). Neural and biomechanical tradeoffs associated with human-exoskeleton interactions. Appl Ergon, 96, 103494. https://doi.org/10.1016/j.apergo.2021.103494