Psychomotor Skills for the 21st Century:

What should students learn?

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Introduction

It is widely recognized that technology is changing the world of work.[1] With advances continuing at a rapid pace, there is a mixture of excitement and fear: changes such as automation, artificial intelligence, and robotics propel our economy forward, while simultaneously displacing workers.[2] At the time of writing, robots are beginning to surpass perceived limitations in dexterity and learning, becoming more human-like in their capabilities.[3,4] A working paper from the National Bureau of Economic Research reports that each additional robot per thousand workers reduces employment by 3 to 5.6 workers and aggregate wages by about 0.25 to 0.5 percent, with the low-ends being in industries that are most exposed to robots.[5] McKinsey Global Institute estimates that by 2030, 30 percent of work in 60 percent of occupations could be automated.[6]

While automation and other technological advancements will undoubtedly shape the future of work across sectors, fear that robots will replace humans have so far been misplaced. In fact, "despite extensive automation since 1950, it appears that only one of the 270 detailed occupations listed in the 1950 Census was eliminated thanks to automation – elevator operators;"[7] and, in fairness, one can still find elevator operators in New York City. The critical point is that the numbers employed in any given occupation might be severely impacted by technology as the modernization of society will render some jobs obsolete and push others to evolve. Neither blue collar nor white collar jobs are immune to the effects of technological advancements. Everything from manufacturing to bookkeeping to driving is impacted by technology,[8] and the advent of new and improving technologies will require re-training and re-distribution of work across industries and occupations.

In our earlier publication, Skills for the 21st Century[9], we identified and discussed the cognitive skills students need to thrive in today's society. In this report, the focus is on the psychomotor skills necessary for success in work and life. To best prepare students for this changing world, it is most useful to ask: **what psychomotor skills are least likely to be replaced by technological advancements?** And, **what psychomotor skills are needed to thrive in this continuously evolving,**

[1]Frey, C. B., & Osborne, M. A. (2017). The future of employment: how susceptible are jobs to computerisation?. Technological Forecasting and Social Change, 114, 254-280.
[2] Autor, D. H., Levy, F., & Murnane, R. J. (2003). The skill content of recent technological change: An empirical exploration. The Quarterly Journal of Economics, 118(4), 1279-1333. Retrieved from https://economics.mit.edu/files/11574
[3] Knight, W. (March 26 2018). Exclusive: This is the most dexterous robot ever created. MIT Technology Review. Retrieved from https://www.technologyreview.com/s/610587/robots-get-closer-to-human-like-dexterity/
[4] Chokshi, N. (April 18, 2018). Robot Conquers One of the Hardest Human Tasks: Assembling Ikea Furniture. *New York Times*. Retrieved from https://www.nytimes.com/2018/04/18/science/robots-ikea-furniture.html
[5] Acemoglu, D., & Restrepo, P. (2017). Robots and jobs: Evidence from US labor markets. Retrieved from http://www.sipotra.it/wp-content/uploads/2017/04/Robots-and-Jobs-Evidence-from-US-Labor-Markets.pdf
[6] Manyika, J., Lund, S., Chui, M., Bughin, J., Woetzel, J., Batra, P., Ko, R. & Sanghvi, S. (December 2017). *Jobs lost, jobs gained: Workforce transitions in a time of automation.* McKinsey Global Institute. Retrieved from https://www.mckinsey.com/~/media/McKinsey/Global%20Themes/Future%20of%20Organizations/What%20the%20future%20of%20work%20will%20mean%20for%20jobs%20skills%20and%20wages/MGI-Jobs-Lost-Jobs-Gained-Report-December-6-2017.ashx
[7] Bessen, James E., How Computer Automation Affects Occupations: Technology, Jobs, and Skills (October 3, 2016). Boston Univ. School of Law, Law and Economics Research Paper No. 15-49. Available at SSRN: https://ssrn.com/abstract=2690435 or http://dx.doi.org/10.2139/ssrn.2690435
[8] Brynjolfsson, E and A McAfee (2014) The Second Machine Age: Work, Progress, And Prosperity In A Time Of Brilliant Technologies, New York: WW Norton & Company.
[9] Bialik, M. & Fadel, C. (2015). *Skills for the 21st Century: What Should Students Learn?* Center for Curriculum Redesign. Retrieved from http://curriculumredesign.org/wp-content/uploads/CCR-Skills_FINAL_June2015.pdf

increasingly technological world of work? This paper will justify and explore the Psychomotor Skills necessary for a 21st Century Education, identifying two “meta-motor” abilities as essential: coordination and adaptation.

In crafting this synthesis and proposed framework for thinking about motricity, we reviewed literature from a variety of fields such as education, child development, medicine, sports, workforce development, and the arts. Much of this literature on psychomotor skills is subject and/or occupation bound. While there is information on how to develop psychomotor skills more generally and how to measure their performance more specifically, there is a dearth of research when it comes to identifying universally critical ways of describing psychomotor skills.

This paper proposes a new way of thinking about motricity. To facilitate this discussion, one must first revisit traditional classifications of psychomotor skills.

Taxonomy for psychomotor learning

Traditional Classifications

The most common classification of psychomotor skills is “gross” and “fine.” Gross motor skills are defined as those that involve larger groups of muscles (for example, arms or legs), while fine motor skills are those that involve smaller groups of muscles such as those found in fingers.[10] Within these two broader categories of psychomotor skills there are countless context- and job- specific skills to master, such as: assembling parts, operating controls, putting in an IV, using a scalpel, typing, reaching, lifting, and walking.

In practice, most movements require a combination of gross and fine motor skills. Even writing, often identified as a fine motor skill, additionally requires coordination of larger muscle groups in the arm. Consequently, present classifications of skills as either gross or fine, rely on an overly simplistic dichotomy. While acknowledging the advantages of the job-requirement approach used by the used by Programme for the International Assessment of Adult Competencies (PIAAC) and The Occupational Information Network (O*NET)[11] to assess psychomotor skills, it is also of note that these popular data sets rely on the fine/gross motor skill dichotomy and thus focus their assessment on vague sub-categorizations of movement (e.g., physical v. skilled manual tasks), missing the complexity inherent in psychomotor skills.[12]

[10] Cratty, B.J. & Noble, C.E. (April 2016). Psychomotor learning. Encyclopædia Britannica online. Retrieved from https://www.britannica.com/science/psychomotor-learning/Individual-and-group-differences
[11] Borelli, S. (2016). How Workers' Skills Are Used at Work: A Multi-Country Comparison with PIAAC (No. 5/16). Retrieved from http://www.diss.uniroma1.it/sites/default/files/allegati/DiSSE_Borelli_wp5_2016.pdf
[12] Spiezia, V. (2016, June). Skills for a Digital World. Panel at OECD Ministerial Meeting on the Digital Economy, Cancún, Mexico. Retrieved from https://ec.europa.eu/jrc/sites/jrcsh/files/JRC_J3_PREDICT%202016-02%204_OECD%20eSkills%20-%20V%20Spiezia.pdf

While Bloom's Taxonomy identifies Psychomotor as one of three domains of educational activities,[13] the committee that created it failed to provide a progression for development of these skills, noting lack of expertise in the area.[14] Others[15,16,17] have filled this gap, proposing their own taxonomies for thinking about the development of psychomotor skills.

Review of work on development of psychomotor skills revealed some confounding factors. Existing progressions posit a linear way of thinking about the development of a skill; however, they tended to describe performance measures (e.g., precision or stamina) as well as higher level coordination and/or adaptation of skills as unique developmental stages. We argue that doing so confounds multiple aspects of psychomotor learning, forcing activities that develop on parallel tracks to be conceived of on a singular track.

On the scale of development of a single skill, one simple way to conceptualize learning comes from the conscious competence model[18] (Figure 1). Two factors are relevant in this model: conscious awareness and degree of competence. In the first stage, Unconscious Incompetence, the goal is not conceptualized, and so they can't properly use feedback. In other words -- if one doesn't know what it feels like to be balanced, then one doesn't know how to work toward being balanced.

Once a learner becomes aware of the goal, they become aware of their own incompetence. With practice, they can become competent (defined by many different measures, as we'll discuss below), but it will take conscious attention to the task. With even more trial and error practice, the competence becomes unconscious.[19] This unconscious competence can become part of a different skill's unconscious incompetence when a new aspect is involved, for example, one can unconsciously and

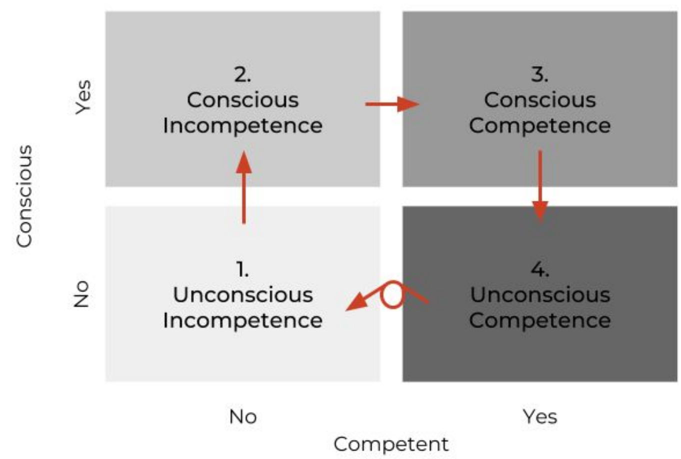

Figure 1: Conscious Competence model
Source: Adapted from Cannon et al 2014

[13] Bloom, B.S. (Ed.). Engelhart, M.D., Furst, E.J., Hill, W.H., Krathwohl, D.R. (1956). Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain. New York: David McKay Co Inc.
[14] Clark, D. (2015). Bloom's Taxonomy of Learning Domains. A Big Dog, Little Dog and Knowledge Jump Production. Retrieved from http://www.nwlink.com/~donclark/hrd/bloom.html
[15] Simpson E.J. (1972). The Classification of Educational Objectives in the Psychomotor Domain. Washington, DC: Gryphon House.
[16] Harrow, A. (1972) A Taxonomy of Psychomotor Domain: A Guide for Developing Behavioral Objectives. New York: David McKay.
[17] Dave, R.H. (1970). Psychomotor levels in Developing and Writing Behavioral Objectives, pp.20-21. R.J. Armstrong, ed. Tucson, Arizona: Educational Innovators Press.
[18] Cannon, H. M., Feinstein, A. H., & Friesen, D. P. (2014, January). Managing complexity: applying the conscious-competence model to experiential learning. In Developments in Business Simulation and Experiential Learning: Proceedings of the Annual ABSEL conference (Vol. 37).
[19] These stages line up with the way other psychomotor frameworks have described various stages. For example, unconscious competence has been described as Naturalization, everything unconscious has been described as reflexive, and everything conscious as reactive.

competently keep rhythm, but fail to realize that they lose the rhythm on the offbeats. The development of this new skill (or transfer of an old skill, depending on how one wants to categorize it based on the larger goals) begins with becoming aware of the unconscious incompetence built on the previous skill's unconscious competence. One can then move through the entire progression with this new yet related skill.

Feedback for psychomotor learning: Perception and proprioception

Typically found early on in psychomotor progressions as precursors to more advanced stages of movement, perception and proprioception are identified herein as critical aspects of a feedback loop in motricity, *not* developmental stages unto themselves as some[20] [21] have claimed. **Perception** is awareness gained through the five senses (sight, hearing, smell, taste, and touch). **Proprioception** refers to one's awareness of their body in space.[22] In order to develop in any given skill, one needs the ability to receive, interpret, and ultimately act on perceptive or proprioceptive input, creating a feedback loop that facilitates the refining of movement.[23] In this sense, perception and proprioception are not specific steps in the development of psychomotor skills, rather they are continuous mechanisms for feedback[24], which is necessary to refine one's psychomotor skills and facilitate transfer of these learned skills to new domains.[25] In other words, they create the conditions necessary for trial and error to take place, so that one may move from unconscious incompetence through unconscious competence. In the highest level, perception and proprioception are key in coordinating movement, as conscious awareness plays less of a role, and movement is determined based on input.

Measures of Motor Skills

To have productive discussions about motricity and how to best facilitate psychomotor learning, it is critical to move beyond the status quo's simplistic dichotomy of gross and fine psychomotor skills, toward thinking about motor skills in general as **laying on several continua that correspond to various dimensions of performance relevant to the task at hand.** Doing so emphasizes the inherent complexity of movement and the important role measurement plays in defining and categorizing skills.

As outlined in the table below, measures of psychomotor performance found across many frameworks include attributes such as precision, accuracy, speed, and consistency, as well as physical abilities such as strength, flexibility, balance, and stamina. These metrics can be used to assess development of psychomotor skills within and across jobs, placing individuals on a set of performance continua uniquely weighted to reflect the task at hand. For instance, tightening a screw would be high on precision whereas moving a box would rank low.

[20] Simpson E.J. (1972). The Classification of Educational Objectives in the Psychomotor Domain. Washington, DC: Gryphon House.
[21] Harrow, A. (1972) A Taxonomy of Psychomotor Domain: A Guide for Developing Behavioral Objectives. New York: David McKay.
[22] Aman, J. E., Elangovan, N., Yeh, I., & Konczak, J. (2015). The effectiveness of proprioceptive training for improving motor function: a systematic review. Frontiers in human neuroscience, 8, 1075.
[23] Cooper, W. E. (1976). Evaluating Motor and Perceptual-Motor Development: Evaluating the Psychomotor Functioning of Infants and Young Children. Retrieved from https://files.eric.ed.gov/fulltext/ED126001.pdf
[24] In some cases, it may be more accurate to discuss "feed-forward" systems
[25] Osborne, E. D. (1986). Teaching Strategies for Developing Psychomotor Skills. NACTA Journal, 30(1), 54-57.

Measure	Description
Precision	Degree of exactness
Accuracy	Achieving intended outcome
Speed	Time to achieve outcome
Strength	Power to move objects and/or perform physically demanding tasks
Flexibility	Range of motion
Balance	Maintaining stability (static and dynamic)
Stamina	Sustaining physical effort
Consistency	Parameters above, over time

Table 1: Measures of psychomotor skill, from across sources
Source: CCR

Meta-motor abilities

So far the discussion has focused on the development of a single motor skill. In practice, however, it can be quite difficult to separate complex skills and their various dimensions. For instance, one may be quite adept at running--perhaps it is second nature--but cannot run and dribble a basketball. Running and dribbling a basketball are two separate skills, at which one may be at different levels developmentally. The level of competence in one is irrelevant to level of competence of the other.

Like perception and proprioception, **coordination** and **adaptation** are not stages in the development of a psychomotor skill, but rather reside outside of, and apply across, that general progression. Whereas perception and proprioception are feedback mechanisms, coordination and adaptation are meta-motor skills, since they can apply to skills that have been developed to various levels of proficiency.

Coordination

Combining psychomotor skills can happen **within a given time** (such as running and dribbling a basketball) or it can happen **across time** (such as sequencing together the skills involved in building a car engine).[26] Assembling, typing, styling hair, and even more simple tasks such buttoning or zipping clothing all require a degree of coordinated movement.[27] The capacity for coordinated movement allows us to create patterns of movement to achieve a desired result.[28] This is a critical skill in

[26] Cooper, W. E. (1976). Evaluating Motor and Perceptual-Motor Development: Evaluating the Psychomotor Functioning of Infants and Young Children. Retrieved from https://files.eric.ed.gov/fulltext/ED126001.pdf
[27] U.S. Department of Labor. (2012) O*NET Ability Profiler User's Guide. U.S. Department of Labor, Employment and Training Administration. Retrieved from https://www.onetcenter.org/dl_tools/AP_zips/AP-UG-deskp.pdf
[28] Clifford, M. (1985). U.S. Patent No. 4,508,510. Washington, DC: U.S. Patent and Trademark Office.

everything from surgery to dance. As discussed above, perception and proprioception play a critical role here in providing feedback.

Recent advances have demonstrated significantly improved coordination in robots[29], an area that has been a pain point in development. Within the context of automation and robotics, coordination (and, particularly hand-eye coordination) is especially difficult, and critical to future progress. Perception and manipulation have previously been identified as bottlenecks in development, more specifically the precisely coordinated movement of fingers is an area in which humans retain the competitive advantage.[30] More broadly speaking, our ability to say, climb a ladder while carrying equipment that will then be used to install solar panels is an example of coordination that has been difficult for our technological counterparts to replicate. These “non-routine” tasks, which do not rely on explicit instructions, require greater coordination (in terms of sequencing) and also adaptation (covered in the next section), and are among those that, despite gains in dexterity, are less likely to be replaced by technology in the near future.[31]

Adaptation (aka Transfer)

Psychomotor skills, like cognitive skills, requires the ability to transfer skills to different contexts. The context a skill is learned in and the context it must be transferred to may be near (share many features in common), or far (share fewer or deeper features in common). Change is also not unilinear. There are various dimensions that can be changed about the context, such as the environment the task must be performed in, the criteria of particular aspects of the task, and the medium involved. The table below shows three types of changes to context that necessitate transfer, and examples of corresponding near and far transfer tasks. These types are not exhaustive nor are they mutually exclusive.

	Near Transfer	Far Transfer
Environment	building a circuit in a lab → building a circuit on a ladder	building a circuit in a lab → building a circuit on a ladder in the rain
Criteria	picking up a box once → picking up a box 5 times	picking up a box → picking up a box 50 times
Medium	typing on a computer → typing on a tablet	playing piano → playing the flute

Table 2: Near and Far Transfer
Source: CCR

When considering the difficulty of transfer, it is important to consider both how many factors are varied, and how much they’re varied. For example, learning to play the flute after having learned the

[29] Goglowski, N. (February 13, 2018). A Boston Dynamics Robot Has Figured Out Door Levers. Sleep Tight! *Huffington Post.* Retrieved from https://www.huffingtonpost.com/entry/boston-dynamics-robot-opens-doors_us_5a830328e4b0892a0353768d
[30] Conseil d’Orientation pour l’Emploi. (June 6, 2017). Automation and its implications on skills use and training. [PowerPoint slides]. Retrieved from http://www.coe.gouv.fr/IMG/pdf/COE_GQ_Paris_6_June_2017.pdf
[31] Autor, D. H., Levy, F., & Murnane, R. J. (2003). The skill content of recent technological change: An empirical exploration. The Quarterly Journal of Economics, 118(4), 1279-1333. Retrieved from https://economics.mit.edu/files/11574

piano, one may be able to appreciate differentiation of sound production in fingering, but have difficulty with the motor skills involved in embouchure

Within the context of automation and robotics, transfer is especially critical as creating perceptive/proprioceptive feedback loops for robots is exceptionally difficult -- this again invokes routine versus non-routine tasks. Routine tasks are easily programmed, but do not account for changes in environment. Sensory input is critical to transfer as it allows one to adjust their movement to meet the specific requirements of a situation.

Take for instance, another engineering bottleneck that has been identified: working in cramped spaces and/or awkward positions.[32] Perhaps one knows how to install a lightbulb. Can they get into a crawl space and install a lightbulb, with limited room to move about, perhaps in a reclined position, and dim lighting? To achieve that non-routine task requires transfer. Being adept at navigating environmental demands is critical to effectively operating in the 21st century, and “varying just one aspect of a motor task—the size of an object, the height, slope, or texture of a surface—requires adaptation (transfer) of movements to conform to new environmental conditions.”[33]

Far transfer, for instance being able to more easily learn to play the flute because one is trained at the piano, is additionally critical because as the world of work continues to evolve and be shaped by technology, the ability to transfer one’s psychomotor skills to fulfill new job functions is essential. The change will in many cases be akin to going from being able to perform heart surgery to being able to perform robotically-assisted heart surgery.

Meta-Motor Development

Similar to motor skills, meta-motor abilities can also move through a learning progression. One can be unconscious of their inability to combine skills, they can become conscious, they can become capable, and they can become unconsciously capable. Likewise, both coordination and adaptation can be measured according to attributes outlined in the preceding section. In essence, motor skills and meta-motor abilities operate the same way. The critical difference is that “meta-motor” indicates an additional combination or nuance to the skill.

[32] Conseil d’Orientation pour l’Emploi. (June 6, 2017). Automation and its implications on skills use and training. [PowerPoint slides]. Retrieved from http://www.coe.gouv.fr/IMG/pdf/COE_GQ_Paris_6_June_2017.pdf
[33] Trawick-Smith, J. (2014). The physical play and motor development of young children: A review of literature and implications for practice. Center for Early Childhood Education Eastern Connecticut State University. Retrieved from http://www.easternct.edu/cece/files/2014/06/BenefitsOfPlay_LitReview.pdf

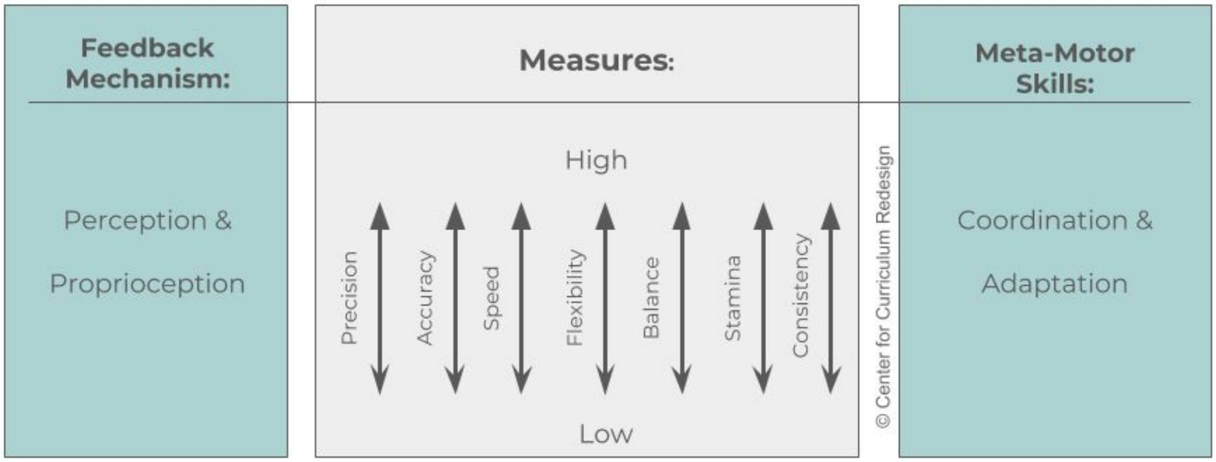

Figure 2: Summary of CCR Psychomotor Skills framework
Souce: CCR

A typical complex coordinated skill progression may involve breaking the skill down into smaller skills, developing them to some degree of conscious competence, and then combining them and developing the coordinated skill. For example, in learning a piano composition, one must first learn each hand separately, and then put them together (that is, before they reach unconscious competence sight reading). Similarly, a typical way of developing a task that must be versatile would be to develop it in one context until it reaches a degree of conscious competence, and then begin developing it in other contexts. Thus, measures apply to psychomotor skills as well as meta-motor abilities.

Conclusion

Psychomotor skills represent "How we use our motricity." Some degree of motricity is required to function in society at the most basic level. As our economy continues to evolve and technology advances, we will continue to observe shifts in what psychomotor skills are demanded by employers and for future success. Meta-motor abilities are likely to withstand these shifts. In other words, while the base "motor skills" necessary for success in the 21st century may dramatically change, despite those changes, one will need to be able to coordinate and adapt these skills. In fact, it is our ability to coordinate and adapt that will allow us to evolve with the world's technological advancements.

In this paper, a new way of thinking about motricity was presentented. It posits:

1) perception and proprioception are critical feedback mechanisms for psychomotor development,

2) psychomotor skills cannot be accurately categorized as fine or gross but rather should be defined based on measurable attributes, and

3) singular psychomotor skills have a linear progression from unconscious incompetence to unconscious competence, that is independent of their combination with additional skills or transfer to new situations, which can also have their own developmental progressions.

In using these three guiding principles to review diverse bodies of literature on motricity, two essential psychomotor skills that transcend fields emerged--**coordination and adaptation**. These are referred to as “meta-motor” abilities because they can be applied to any psychomotor skill, transcending typical subject- and/or occupation-bound categorizations.

Although psychomotor skills are presented separately from cognitive skills and knowledge, research suggests a link between motor development and cognitive development in children experiencing linguistic delays, even suggesting that motor development is a “prerequisite for cognitive development and academic learning”[34,35] While overall there is weak evidence of correlation between motor and cognitive skills, results do suggest potential for interventions to stimulate high order cognitive along with motor skills.[36] In fact, a recent study out of Germany found that “fostering the children’s physical fitness during the primary school age could enhance both motor and cognitive learning abilities related to the academic achievement.”[37] Coupled with the rise in instructional strategies such as experiential and inquiry-based learning which often incorporate hands-on and other sensory approaches, it is easy to imagine reaping the benefits of combining psychomotor and cognitive skill development.

[34] Rintala, P., Pienimäki, K., Ahonen, T. I. M. O., Cantell, M. A. R. J. A., & Kooistra, L. I. B. B. E. (1998). The effects of a psychomotor training programme on motor skill development in children with developmental language disorders. Human Movement Science, 17(4-5), 721-737.

[35] Bushnell, E. W., & Boudreau, J. P. (1993). Motor development and the mind: The potential role of motor abilities as a determinant of aspects of perceptual development. Child development, 64(4), 1005-1021.

[36] van der Fels, I. M., te Wierike, S. C., Hartman, E., Elferink-Gemser, M. T., Smith, J., & Visscher, C. (2015). The relationship between motor skills and cognitive skills in 4–16 year old typically developing children: A systematic review. Journal of Science and Medicine in Sport, 18(6), 697-703.

[37] Abdelkarim, O., Ammar, A., Chtourou, H., Wagner, M., Knisel, E., Hökelmann, A., & Bös, K. (2017). Relationship between motor and cognitive learning abilities among primary school-aged children. Alexandria Journal of Medicine, 53(4), 325-331.

Appendix: Major Psychomotor Taxonomies

The following table shows three main syntheses of psychomotor skills to date, and the way they fit into the analysis of this paper.

Dave (1975)		
Category	***Description***	***CCR Commentary***
Naturalization	Mastery/second nature	Unconscious Competence
Articulation	Coordinate + adapt a series harmoniously	Meta-Motor
Precision	More refined/exact	Measure
Manipulation	Perform based on memory or instructions	Trial and Error: Unconscious Incompetence, Conscious Incompetence, or Conscious Competence
Imitation	Observe + replicate with variable quality	
Simpson (1972)		
Category	***Description***	***CCR Commentary***
Origination	Create new pattern for specific situation	Meta-Motor
Adaptation	Well-developed; can modify for specific requirements	
Complex Overt Response	Skillful, complex, coordinated movement	
Mechanism	Habitual, confidence, basic proficiency	Conscious Competence
Guided response	Imitation, practice, trial/error	Conscious Incompetence
Set	"Readiness to act" - mentally, physically, and emotionally	Prerequisite
Perception	"Use sensory cues to guide motor activity"	Prerequisite and ongoing feedback mechanism
Harrow (1972)		
Category	***Description***	***CCR Commentary***
Non-discursive communication	"effective body language, such as gestures and facial expressions"	Specific subset of motor skills

Skilled Movements	Advanced movements including adaptation and integration	Meta-Motor
Physical Activities	Stamina, fitness	Measure
Perceptual	"Response to stimuli"	Prerequisite and ongoing feedback mechanism
Basic Fundamental Movement	Simple tasks (e.g., walking)	Unconscious Competence (for tasks considered simple)
Reflex Movements	Automatic/not learned/involuntary	N/A

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