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Compulsory Physical Activity in Higher Education Specifies Hours but Not Cognitive Demand: Implications for Students' Executive Function

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Abstract

Introduction: *Universities that require physical activity specify it in two units: contact hours and, where outcomes are assessed at all, fitness test scores. Course documents are silent on what students do while the hours accumulate. Yet experimental work indicates that the cognitive demand of an activity predicts its effect on executive function at least as well as its metabolic cost does, and that metabolically matched activities differ substantially in cognitive outcome. This review asks why such a variable remains outside the course specification, the instrument and the report.*

Methodology: *This is a critical narrative review. We assembled a purposive collection of experimental studies in young adults contrasting cognitively engaging with metabolically matched control activities, syntheses of intervention effects on cognition, and methodological literature on physical activity measurement. Sources illustrate conceptual or measurement decisions rather than forming a representative sample; no pooled estimate is produced.*

Themes and findings: *Seven themes are developed. The dose paradigm is a measurement inheritance before it is a theoretical position: accelerometry resolves intensity, and what an instrument resolves becomes what a curriculum states. The evidence that kind matters is stronger than its uptake suggests, because the decisive comparisons hold metabolic load constant. "Cognitively engaging" is a portmanteau covering four separable dimensions — coordinative complexity, decision demand, novelty and social-interactive demand — which studies vary independently under one label. Cognitive and physical load may compete rather than sum, predicting an untested interaction. The same activity imposes different demand on students of differing sporting experience. Reporting does not permit any of this to be recovered. And a content-sensitive requirement need not sacrifice administrative simplicity.*

Conclusion and recommendations: *We propose a four-dimension description standard for course and intervention content, and argue that qualitative characteristics should be treated as specified and reported variables rather than as incidental features of a timetable.*

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1. Introduction

A large share of the world's undergraduates are required to be physically active as a condition of their degree. China's universities administer compulsory physical education across the first two years and assess students against a national fitness testing standard; Malaysian institutions operate co-curricular credit requirements; and campus recreation participation targets are common elsewhere. In each case the requirement is expressed in the same two units: hours of attendance, and — where any outcome is measured — performance on a fitness battery.

Intensity and duration exhaust the specification, exactly as they do in the public health guidance from which the units are borrowed (Bull et al., 2020). Nothing in a typical course document concerns what the student is doing while the hours accumulate.

For the health outcomes these requirements were built to serve, this is defensible. Cardiometabolic adaptation responds to metabolic load, and metabolic load is what intensity and duration jointly express. In that domain the specification is adequate.

The difficulty arises when the same frame is used to justify cognitive and academic claims — and universities increasingly make them. Compulsory physical activity is defended in institutional documents on the grounds that it supports concentration, academic performance and student wellbeing. The literature on physical activity and executive function has largely adopted the units of the health literature: interventions are described by intensity and duration, and meta-analyses code dose as a moderator. The implicit model is that cognitive benefit, like cardiometabolic benefit, is a function of how much.

A body of experimental work suggests otherwise. When participants perform activities matched on metabolic load but differing in cognitive demand, the more cognitively demanding condition has repeatedly produced the larger effect on executive function (Moreau et al., 2015; O'Leary et al., 2011). Reviews addressing the qualitative characteristics of activity have argued for over a decade that the field's quantitative frame is too narrow (Tomporowski & Pesce, 2019; Pesce, 2012), and syntheses of intervention effects have converged on the view that the content of an intervention matters and that content is not captured by dose (Ludyga et al., 2020; Diamond & Ling, 2016).

The argument is not new. What is striking is how little it has changed practice. Course specifications remain silent on activity content. Measurement instruments do not capture it. Intervention reports describe it in prose that cannot be coded. Meta-analyses that code intensity and duration as moderators seldom code cognitive demand, because the primary studies do not supply it in codable form.

This review asks why. We argue that the persistence of the dose paradigm in cognitive research is not principally a theoretical commitment but a measurement inheritance, and that the label

under which the alternative has been advanced — cognitively engaging physical activity — has itself become an obstacle, because it bundles several distinct manipulations under one name. The review's constructive proposal is that the bundle be unpacked into separately specified, separately reported dimensions.

Two clarifications forestall predictable objections. We do not argue that dose is irrelevant. Metabolic load almost certainly contributes to cognitive outcomes, directly through the physiological pathways that support neural function and indirectly by making sustained participation possible, and the health case for existing requirements stands independently of anything argued here. Nor do we argue that the qualitative literature has established the size of the content effect; Section 3.3 explains why the sources we draw on cannot support such an estimate. The argument is about what is specified, measured and reported — about whether a variable that the available evidence identifies as consequential is permitted to enter the record in a form that allows it to be studied.

We restrict attention to university students and comparable young-adult samples, and to executive function rather than cognition in general.

2. Literature review

2.1 The construct and the outcome

Executive function comprises inhibition, updating of working memory and cognitive flexibility — separable components whose structure was established in undergraduate samples (Diamond, 2013; Miyake et al., 2000). Individual differences in executive function predict academic outcomes in higher education, and the construct is plausibly modifiable, which is why it has become the principal cognitive target of physical activity research.

2.2 The dose evidence

Syntheses of fitness, exercise and cognition report positive but modest associations across designs, beginning with Etnier et al. (1997) and extended by later work identifying moderators of long-term effects in healthy individuals (Ludyga et al., 2020). Reviews of the underlying neuroscience have linked habitual activity and cardiorespiratory fitness to the structure and function of the networks supporting cognitive control (Hillman et al., 2008). This body of work supports the general proposition that more activity is better, and it is the empirical foundation on which the dose frame rests in the cognitive domain.

2.3 The qualitative alternative

A parallel literature has argued that what is done matters as much as how much. Pesce (2012) made the general case for shifting attention from quantitative to qualitative exercise characteristics. Tomporowski and Pesce (2019) subsequently proposed that exercise, sport and performance arts may benefit cognition through a common process that is not reducible to metabolic load. Diamond and Ling (2016) reviewed interventions across domains and concluded that those engaging the mind alongside the body were the more effective.

The decisive empirical contributions are those that hold metabolic load approximately constant. O'Leary et al. (2011) compared single bouts of aerobic exercise, exergaming and sedentary videogame play in young adults, using behavioural and electrophysiological indices of cognitive control, and found that the conditions were not interchangeable in their cognitive consequences. Moreau et al. (2015) contrasted complex motor training with an aerobic comparison in adults and reported advantages for the condition carrying greater coordinative and decision demand. Budde et al. (2008) had earlier shown that acute coordinative exercise improved attentional performance relative to a control bout, and Benzing et al. (2016) reported comparable findings using an exergame protocol in which cognitive demand was manipulated within an activity of matched physical intensity — both in adolescent samples, which we note as a limitation on transfer to undergraduate populations.

Adjacent evidence points the same way. Athletes in sports with high perceptual-cognitive demand show cognitive profiles that are not straightforwardly explained by fitness (Voss et al., 2010), and comparative reviews of athletic and computerised training have argued that the combination of physical and cognitive demand may be more potent than either alone (Moreau & Conway, 2013).

The open-skill and closed-skill distinction inherited from motor learning offers the closest thing the field has to an established vocabulary for one of these dimensions. Open skills are performed in an environment that changes unpredictably and therefore require continuous perception, anticipation and response selection; closed skills are performed in a stable environment and can be executed from a pre-specified pattern. A systematic review of open- versus closed-skill exercise found the distinction to carry cognitive consequences (Gu et al., 2019), which is precisely the dissociation a purely metabolic account cannot accommodate. The distinction is, however, binary where the underlying variable is continuous, and it captures only decision demand — leaving coordinative complexity, novelty and social interaction unaddressed. It is a useful precedent rather than a sufficient scheme.

2.4 The gap

The two literatures have not been integrated at the level that matters for institutional practice. Course requirements specify hours. Instruments measure intensity. The qualitative literature makes its case in the language of contrasts between named programmes rather than in the language of specified variables. As a result there exists no agreed vocabulary in which the cognitive demand of an activity can be stated, and consequently no way to code it in a meta-analysis, prescribe it in a curriculum document, or reproduce it in a replication.

3. Methodology

3.1 Type of review

This is a critical narrative review. Its object is a conceptual and measurement practice, not an effect size, and its aim is to reorganise a set of claims rather than to pool them. No protocol was registered, the search was not exhaustive, and no quantitative synthesis is offered. A

systematic review would be the right instrument for asking how large the engagement effect is; it is not the right instrument for asking why the variable has no agreed definition.

3.2 Sources and selection logic

Three source types were assembled purposively. The first comprises experimental studies in young adults that contrast conditions differing in cognitive demand while holding physical load approximately constant, since these carry the argument's evidential weight. The second comprises reviews and syntheses of physical activity effects on cognition, selected to represent the range of positions on whether content matters. The third comprises methodological literature on physical activity measurement, used to support the claim in Section 4.1 about measurement affordances.

Descriptions of study designs are taken from the studies' own reporting. Where an intervention's content could not be reconstructed from the published account, we treat that as data bearing on Section 4.5 rather than as a reason to exclude the study.

3.3 Limitations of the approach

Purposive selection may over-represent studies reporting positive engagement contrasts, since such studies are both more likely to be published and more likely to be cited in the reviews from which the collection was assembled. This is a material limitation for any claim about the size or reliability of the engagement effect, and we accordingly make no such claim. The review's argument is that the variable is unspecified and unreported, which does not depend on the effect's magnitude. Two of the metabolically matched contrasts we cite were conducted in adolescents rather than undergraduates, and we flag that transfer as an assumption rather than a finding. Single-reviewer selection introduces the usual risk of unrecognised bias.

4. Themes and findings

4.1 The dose paradigm is a measurement inheritance

The most economical explanation for the dominance of intensity and duration is not that researchers or curriculum designers believe cognitive demand to be unimportant. It is that intensity and duration are what the field's instruments return.

An accelerometer measures acceleration at the point of attachment. Raw acceleration is converted to counts, counts are aggregated over an epoch, and epoch-level counts are classified into intensity categories by a calibration equation (Migueles et al., 2017; Sasaki et al., 2011). The output is a distribution of time across intensity bands. This is a genuine achievement, and it made population surveillance possible. But it fixes the vocabulary. A device that resolves intensity produces a literature in units of intensity, a requirement stated in units of intensity, and an evaluation framework that asks whether provision moved minutes between bands.

Cognitive demand has no equivalent instrument. It cannot be inferred from acceleration, because two activities producing identical acceleration traces — running a shuttle course to a

fixed pattern, and running the same course while responding to unpredictable signals — differ in exactly the respect at issue. There is no wearable that distinguishes them.

The consequence is a quiet substitution. What can be measured becomes what is required; what is required becomes what is evaluated; what is evaluated becomes what departments are asked to deliver. At no point is a judgement made that cognitive demand does not matter. It is simply never entered into the ledger. Self-report instruments do not escape the problem, although they could in principle. A questionnaire is not restricted to what a device can resolve; it can ask what the student was doing, with whom, and under what rules. In practice, such instruments have been built to reproduce the accelerometer's output — minutes at each intensity, sometimes by domain — because comparability with device-based estimates has been treated as the criterion of a good instrument. The questionnaire has been calibrated against the device, and has thereby inherited the device's blind spot rather than compensating for it.

Recognising this as an instrument effect rather than a theoretical position matters, because it identifies the remedy: not better devices, but designed and reported description. The information required is not physically inaccessible. It is known to whoever wrote the syllabus, and it is lost only because nothing in the reporting or specification conventions asks for it.

4.2 The contrast that carries the argument

Much of the evidence adduced for the importance of activity content is weaker than its proponents suggest, because it compares a rich programme with an inactive control and so cannot separate content from activity itself. The studies that carry the argument are those that match physical load and vary cognitive demand alone (Benzing et al., 2016; Moreau et al., 2015; O'Leary et al., 2011; Budde et al., 2008). Where such comparisons have been made, the engagement contrast has generally favoured the more demanding condition, sometimes with the metabolically matched aerobic condition showing no reliable advantage at all.

The logical force of this design deserves emphasis. If dose were the operative variable, matched conditions should produce matched outcomes. They do not. That observation is not compatible with a purely metabolic account, and it is not answered by pointing to the larger literature showing that activity in general is beneficial, because that literature does not include the relevant contrast.

Two cautions are nonetheless warranted. The number of well-matched contrasts in young adults remains modest, and matching on average intensity does not guarantee matching on the full physiological profile — a decision-rich condition may involve different acceleration and deceleration patterns even at equal mean intensity. The claim that survives both cautions is a conditional one: within the range of protocols so far compared, cognitive demand accounts for outcome variance that dose does not.

4.3 Four dimensions under one label

"Cognitively engaging physical activity" names a family, not a variable. Inspection of the activities so labelled suggests at least four separable dimensions, set out in Table 1.

Coordinative complexity concerns the motor demand of the movement itself — bilateral coordination, balance, rhythmic organisation, fine control of force and timing. Perceptual-cognitive decision demand concerns the informational structure of the task — whether the performer must read a changing environment and select among options under time pressure, as in open-skill activities, or execute a pre-specified pattern, as in closed-skill activities. Variability and novelty concern how far the task changes across repetitions and how much of it is unfamiliar. Social-interactive demand concerns coordination with, and anticipation of, other people.

These dimensions can be varied independently, and a university activity catalogue varies them all without saying so. A weight-training module is low in decision demand and social interaction. A badminton module is high in decision demand and moderate in coordinative complexity. A dance module is high in coordinative complexity and novelty. All three may be credited identically, at the same contact hours, and recorded as equivalent.

The problem this creates for research is one of comparability. Two studies may each describe their intervention as cognitively engaging while manipulating different dimensions, and a null result in one is then read as failing to replicate the other when the two never tested the same thing. Meta-analytic coding inherits the confusion, since the only available code is the label. The dimensions may also differ in which executive function component they engage — decision demand plausibly loading on inhibition and flexibility, novelty on updating — a mapping that current reporting makes untestable.

Table 1 is offered as an analytical scheme rather than a validated taxonomy. Its function is to make the dimensions separately statable, which is the precondition for their being separately tested.

Table 1: Four dimensions bundled under the label "cognitively engaging physical activity"

Dimension	What is varied	Illustrative high-demand module	Illustrative low-demand module	Executive component most plausibly engaged
Coordinative complexity	Motor demand of the movement itself: bilateral coordination, balance, rhythm, force and timing control	Dance; gymnastics	Treadmill or stationary cycling	Updating; motor-cognitive integration
Perceptual-cognitive decision demand	Whether the performer must read a changing environment and select among options under time pressure	Badminton; basketball	Weight training to a fixed programme	Inhibition; cognitive flexibility
Variability and novelty	Extent to which the task changes across sessions and is unfamiliar	Rotating introduction to unfamiliar sports	Repetition of one activity across a semester	Cognitive flexibility; updating
Social-interactive demand	Requirement to coordinate with and anticipate other people	Team sport requiring role negotiation	Individual circuit performed in parallel	Inhibition; social-cognitive regulation

Source: Developed for this research, drawing on Gu et al. (2019), Tomporowski and Pesce (2019), Diamond and Ling (2016) and Pesce (2012). The scheme is analytical rather than validated; dimensions are expected to correlate in practice.

4.4 Load competition rather than load summation

The implicit model in much of this literature is additive: physical load contributes a benefit, cognitive load contributes a further benefit, and combining them yields more than either. Diamond and Ling (2016) argued along broadly these lines.

But there are grounds for expecting competition rather than summation at the upper end. Performing a cognitively demanding task while under high metabolic load is a dual-task situation, and dual-task costs are well established. Kamijo et al. (2007) showed that exercise intensity and cognitive task difficulty interact rather than combine additively. The reticular-activating hypofrontality account predicts that at sufficient intensity, resources are drawn away from prefrontal function (Dietrich & Audiffren, 2011).

If competition operates, the relation between combined load and benefit is an inverted surface rather than an ascending plane, and the optimum is an intermediate combination rather than the maximum of both. This predicts something practically important and rarely reported: that adding cognitive demand to an already vigorous activity may reduce rather than increase its cognitive benefit, and that the most effective cognitively engaging modules may be those of moderate rather than high physical intensity.

The prediction is testable by a factorial design crossing two or more levels of physical load with two or more levels of cognitive demand. Such designs are uncommon. Most studies compare one engaging condition with one control condition and can therefore estimate neither the surface nor its optimum. We regard this as the most consequential design gap in the area, because the additive and competitive models generate different practical advice and the field currently has no basis for choosing between them.

The competition account also supplies a candidate explanation for a pattern that the additive account finds awkward. Interventions described as cognitively engaging have not produced uniformly positive results, and null findings are usually attributed to implementation failure or insufficient duration. If competition operates, some of those nulls may instead be cases in which the combined load overshot the optimum. Under the additive model this possibility does not arise, and so it is never tested. Its practical consequence is the opposite of the usual remedy: where an engaging module underperforms, the indicated adjustment might be to reduce one of the loads rather than to intensify both.

4.5 The reporting and specification problem

None of the foregoing can be pursued through the published record as it stands, because activity content is not reported in recoverable form — and the same is true of the course documents that govern practice.

A typical research account describes the intervention by programme name, session frequency, session duration and target intensity, and characterises content in a sentence or two of prose. From such an account a reader cannot determine where the intervention sits on any of the four dimensions, whether the comparison condition was matched on physical load, or how much of the session was actually spent under the intended demand. A typical university module descriptor is thinner still: an activity name, contact hours, and an assessment scheme weighted towards attendance and fitness testing.

The delivered-versus-prescribed distinction is easily overlooked. A module may be designed to be decision-rich while spending much of its class time on organisation, instruction and queuing. Reported dose is prescribed dose; delivered dose is rarely measured, and delivered cognitive demand essentially never is. Two institutions may specify identical modules and deliver very different ones.

Table 2 sets out a description standard intended to make content recoverable. It is deliberately modest: it asks for information that whoever designed the activity necessarily possesses, and it does not require new instrumentation.

Table 2: A description standard for reporting the content of physical activity provision with cognitive outcomes

No.	Item	Why it matters
1	Intended level on each of the four dimensions in Table 1, stated for the activity and for any comparison	Makes the manipulation codable and the comparison interpretable
2	Whether physical load was matched across conditions, and by what index	Distinguishes a content contrast from an activity contrast
3	Objectively verified intensity in each condition, not prescribed intensity only	Prescribed and delivered intensity commonly diverge
4	Proportion of session time spent under the intended cognitive demand	Delivered demand is not prescribed demand
5	Time spent on organisation, instruction and waiting	Directly reduces both delivered doses
6	Whether task difficulty was individually adapted or fixed for the class	Fixed difficulty means different demand for different students
7	Session frequency, duration and total programme length	Standard, and retained here for completeness
8	Prior sporting experience of the cohort, reported distributionally	Demand is relational; skill distribution determines delivered demand
9	Executive function components assessed and instruments used	Permits dimension-to-component mapping across studies
10	Any fidelity monitoring conducted, and its results	Without this, a null result cannot be attributed to the activity

Source: Developed for this research.

4.6 The same activity is not the same demand for every student

A dimension of demand is a property of the relation between a task and a performer, not of the task alone. This is elementary, and it has an underexploited consequence for compulsory provision, where enrolment is not selected on prior skill.

Undergraduate cohorts are heterogeneous in sporting background to a degree that school cohorts are not. A badminton module imposes heavy decision demand on a student who has

never played — because reading the shuttle consumes most of the available control capacity — and considerably less on a student with a decade of competitive experience, for whom the same reading is partly automatic. Conversely, a coordinative sequence that a novice cannot attempt at all may be the more demanding task for the experienced student once it is within reach.

Two implications follow. The first concerns interpretation: a study reporting that a given module did or did not affect executive function has established something about that content for that skill distribution, and the result does not transfer to a cohort of different composition even when the syllabus is copied exactly. Prior experience is rarely reported at all, and never as a determinant of the manipulation's strength.

The second concerns design. If demand is relational, then fixing task difficulty for a class guarantees that the intended level is delivered to few of its members — too demanding for some, trivial for others, correctly pitched only in the middle. Individually adaptive difficulty, standard in cognitive training research, is uncommon in physical activity provision; its absence may attenuate effects in exactly the way that group-fixed difficulty attenuates them elsewhere. This is why Table 2 asks whether difficulty was adapted or fixed.

4.7 What a content-sensitive requirement might look like

If the argument to this point is accepted, an obvious objection follows. Credit requirements succeed administratively because they are simple. Contact hours are countable, auditable and comparable across modules; a requirement that asked programme boards to reason about four dimensions of cognitive demand would forfeit exactly that property. The objection has force.

But the choice is not between the present specification and a complicated one. Three intermediate options are available.

The first is separation of purpose. The hours requirement can remain the health requirement, stated as it is now, with a distinct statement covering cognitive and academic claims. Much of the present difficulty arises from a single specification being asked to serve two purposes for which the governing variables differ. Saying so explicitly would cost nothing and would prevent institutions from asserting cognitive benefits that their own specification does not underwrite.

The second is a qualitative supplement rather than a quantitative one. A requirement need not specify levels on four dimensions to be content-sensitive; a programme might simply require that a student's activity credits include at least one module involving unpredictable situations requiring decisions, and at least one involving coordination with others. That is a sentence, not a framework, and it is more auditable than the present arrangement, since a module can be classified on those criteria more readily than its mean intensity can be estimated.

The third applies at the level of the module catalogue. Where an institution already maintains descriptors for every activity module, those descriptors could carry a four-dimension profile at negligible cost, because the classification is done once, centrally, rather than by every

instructor. The catalogue then becomes a research instrument as well as an administrative one: cohorts choosing different profiles become a natural experiment that no additional data collection is required to exploit.

None of these requires the evidence base to be more complete than it is. Each requires only that the distinction between the two purposes be acknowledged, which is the minimum this review is arguing for.

5. Conclusion and recommendations

Compulsory physical activity in higher education is specified in hours. The evidence that its cognitive benefit depends on something else has been available for over a decade and has not entered the specification, the instrument or the report. This review has argued that the reason is not disagreement about the evidence but the absence of a vocabulary in which the variable can be stated, and that the label under which the alternative has been promoted has obscured rather than supplied one.

Three recommendations follow.

5.1 Treat cognitive demand as a specified variable

Those designing activity modules and interventions should state, in advance and in dimensional terms, what cognitive demand the activity is intended to impose and how it differs from alternatives. This converts content from an incidental property of a named activity into a specified variable with a stated level, and it is a precondition for any cumulative account of which dimensions matter for which components of executive function.

5.2 Adopt a description standard

The items in Table 2 should accompany reports of physical activity interventions targeting cognitive outcomes, and their reduced form should accompany module descriptors. They impose no data collection beyond what implementation monitoring and curriculum documentation already require.

5.3 Test the surface, not the point

Factorial designs crossing physical load with cognitive demand are needed to establish whether the two combine additively or competitively. Universities are well placed to run them: module catalogues already contain activities differing systematically on the dimensions at issue, cohorts are large, and academic outcomes are recorded as a matter of course. Until such designs are conducted, advice that activity should engage the mind as well as the body is stated at a level of generality that cannot guide the choice between a demanding game at moderate intensity and a simple one at high intensity — which is the choice a programme board actually makes.

5.4 Limitations

This review is narrative and purposive, and the collection from which it argues is likely to over-represent positive engagement findings. It therefore supports no claim about the magnitude or reliability of the engagement effect. Part of the metabolically matched evidence comes from adolescent rather than undergraduate samples. The four-dimension scheme in Table 1 is an analytical proposal, not a validated instrument; its dimensions are almost certainly correlated in practice, and their empirical separability is an open question that the scheme is intended to make investigable rather than to settle. Finally, we have not addressed whether the qualitative characteristics that matter for acute effects are the same as those that matter for chronic adaptation, a distinction the literature frequently blurs.

A closing observation. Physical activity requirements are among the more durable features of undergraduate curricula, and their durability owes much to their administrative simplicity. The argument here is not that they should be complicated. It is that when a requirement designed for cardiometabolic outcomes is invoked to justify cognitive and academic ones, the invocation carries an assumption — that the same units govern both — which the available evidence does not support and which no institution has explicitly defended.

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