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Assessment of motor skill task performance with a task progress-weighted error measure

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ABSTRACT

A quantitative measure has been developed for the assessment and skill ordering of target-cued motor control and coordination task performances. It is similar to the classical root mean square error (*RMSE*) measure but modified with task progress weighting that attenuates with target proximity to its destination and amplifies as data sampling occurrences accumulate prior to task completion. The measure has the same mathematical form whether the task design is of the tracing type or of the tracking type, and thus can be used in cross task type comparisons. The new measure is applied to a few simple hypothetical task performances in order to illustrate some of its properties, and then applied to actual experimental data from a tracing task and a tracking task to demonstrate its use.

1. Introduction

Evaluation of human motor skill level has a long history and a large volume of literature spanning more than a century, which has been reviewed extensively by Adams [1]. In contemporary times motor performance assessments of various motor skill-based kinematic tasks involving volitional motion and isometric tasks involving volitional force production are important in many diverse areas of research. Examples can be found among fields such as child development [24], cognitive function , [18], learning mechanisms [17], motor cortex brain mapping [22], and gerontology [19] . These types of assessment are also useful in a wide spectrum of practical contexts, including clinical diagnoses [13], rehabilitation progress from neuronal injury [2], ranking individual efforts in certain sports competition [23], and testing the efficacy of various therapy protocols for neurological disorders [7].

Motor skill itself is not a standard kinematic variable with a well-defined physical dimensionality, so investigators wanting to quantify the concept typically need to use proxy variables constructed from rigorously defined and universally understood kinematic components, yet which still reflect the notion of ordered ability level. Some of the older quantitative scoring methods are not wholly analytical, being based on various categorical scales which depend to some extent on the subjective judgment of the evaluator. An example is the use of the Motor Examination section of the Unified Parkinson's Disease Rating Scale (UPDRS) to assess motor performance in patients diagnosed with that neuropathology [21]. However, for motor tasks in which data acquisition instrumentation can be interfaced with computers it is usually possible to assess and quantify proxies for motor performance skill in an objective fashion, shown, for example, in the force control study of [20].

Though kinematic and isometric tasks for assessing both gross motor skills and fine motor skills cover a wide range of activities and design variants, the interest here is focused on two particular spatiotemporal task types that are quite common and which have been used extensively in motor control and motor behavior research. These involve a "performer", (*i.e.*, an individual whose motor performance is being evaluated) and the performer's "position", (*i.e.*, the location of an object under his or her motor control – be it a body part or some external object such as a computer cursor or a stylus tip manipulated through motion or force transduction). This "performer position" nomenclature is used throughout the presentation here.

One of the task types of particular interest is pursuit tracking, in which the objective is that at every data sampling instance the performer's position matches the position of a moving target

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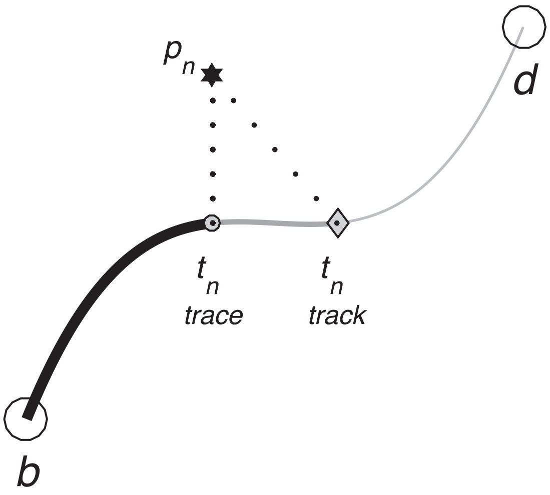

Fig. 1. Components of a dynamic motor control task. A task template consists of a trajectory path starting at beginning point *b* and ending at destination point *d*. At each data sampling instance *n* the task performer establishes a position p_n with an objective of having it coincide with a particular target position t_n on the template. If the task is of a tracking type the position of t_n will be determined *a priori* in the task design. If it is of a tracing type the position of the target t_n will be determined *ad hoc* as the position on the template closest to the current position maintained by the performer.

which has a defined starting point, trajectory, and end point specified as part of the design. Research using this task type has been reported by many investigators and has been comprehensively reviewed by Jones [12]. The second task type is template tracing, in which the objective is that at every data sampling instance the performer's position matches some point on a geometrically fixed and stationary curvilinear pattern with defined start and end positions specified in the design.

Although these two types of tasks can be very similar, particularly if the tracking target's trajectory path coincides with the tracing template's fixed geometry, there is a significant difference between them that makes an ordinal comparison of motor performance quality between a trial from one type and a trial from the other type challenging. This problem arises from the fact that in a tracking task there is a time constraint imposed by a deterministic, design-specified conclusion (either when the accrued sampling instances reach a particular number or when the target has reached its destination), while in a tracing task the target position on the template is a function of the performer's position at every sampling instance and thus subject to strategic manipulation by the performer without a time constraint other than perhaps a general instruction to try to finish the task as quickly as possible while maintaining accuracy. Furthermore, a tracking task is subject to the well-known "speed-accuracy" trade-off, a phenomenon that has been recognized for more than a century and which has been reviewed in detail by Plamondon and Alimi [15]. This complication arises from an inverse correlation between the speed and accuracy in tasks involving target aiming [5], thus impacting tracking tasks where speed is part of the design and is not discretionary, but having little or no impact on tracing tasks where no particular motor performance value is assigned to task speed.

Other more complex variants of motor skill tasks which have a dynamically variable target trajectory or which have the more trivial design consisting of a single stationary point as a target are not being considered here. In the typical motor skill task designs that are being discussed, the template for target positions has a fixed continuous curvilinear trajectory with no bifurcation. A diagram illustrating the components of a single data sampling instance is shown in Fig. 1.

For each data sampling instance *n* there is an associated error h_n, *i.e.*, the absolute linear distance from the performer's position p_n to that of the target t_n. After task completion an objective numerical motor performance evaluation score, by which quality or motor skill level can be ordered, is obtained based on some function or algorithmic processing of the generated sequence of error values. In general, for a task involving *N* data samplings such a scoring function can be formulated in terms of a mean of a task progress weighting of a weighted error function, *i.e.*,

$$Score = F\left[\frac{1}{N}\sum_{n=1}^{N} g(n, z_n) f(h_n)\right]$$

where *g* is a task progress weighting, *f* is a positional error weighting, and the outer function *F* is the inverse operation of the function *f*. The task progress weighting can be a function of either or both the sequence number *n* in the data sampling (*i.e.*, the accrued number of data recordings so far) and the fractional length remaining along a template for the target trajectory at the instant of data sampling. If the target is at t_n, then this remaining fraction z_n can be represented as a ratio of line integrals:

$$z_n = \frac{\int_{C_n} ds}{\int_{C} ds}$$

where C_n is the path from the target position on the template at the *n*th sampling to the destination position, and *C* is the path from the beginning position of the template to the destination position.

The error weighting function *f* itself can be a composition of *k* operations, *i.e.*, $f_k(f_{k-1}\ldots(f_2(f_1)))$, but if so then *F* would need to be a composition of the corresponding inverse operations in reverse order, *i.e.*, $F_1(F_2\ldots(F_{k-1}(F_k)))$.

A motor performance assessment variable based solely on error, without regard to task progress, can be constructed by setting $g(n, z_n) = 1$ for all values of *n* and z_n. A widely used form for error weighting, favored by many researchers for its simplicity and ease of conceptualization, is $f(h_0) = h_0^2$. This assures that there is no canceling out of positive-valued errors with negative-valued errors and keeps the range and resolution of function values reasonable. With *f* then being merely the squaring operation, *F* is in turn the inverse of the squaring operation, *i.e.*, taking the positive square root. The generalized form of the motor performance score thus reduces to

$$Score = F\left[\frac{1}{N}\sum_{n=1}^{N} g(n, z_n) f(h_n)\right] = \sqrt{\left[\frac{1}{N}\sum_{n=1}^{N} h_n^2\right]}$$

which is usually given the descriptive acronym *RMSE*, being a square **R**oot of the **M**ean of the **S**quares of the **E**rrors.

A motor performance assessment variable based solely on task duration while sampling data at rate ω, independent of any error involved, can be constructed by setting

$$g(n, z_n) = \frac{2nN}{\omega(N+1)}$$

and then choosing the error function $f(h_n) = (h_n)^0 = 1$ for all *n*. In this case, the generalized motor performance score reduces to

$$Score = F\left[\frac{1}{N}\sum_{n=1}^{N} \frac{2nN}{\omega(N+1)}\right] = F\left[\frac{N}{\omega}\right] = \sqrt[0]{\frac{N}{\omega}}$$

where *F* is the inverse operation of raising to power zero. However, a zero root is undefined in mathematical terms, so that in this particular case *F* is usually taken to be the equivalent of no operation at all and thus the score is merely the inverse function argument