A Cognitive Modeling Approach – Does Tactical Breathing in a Psychomotor Task Influence Skill Development during Adaptive Instruction?

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Abstract. This paper reports the relationship between cognitive (e.g., attentional resources) and physiological (e.g., breathing) factors in executing a psychomotor task (i.e., golf putting). We explore performance from a series of computational models in the ACT-R and ACT-R/Φ architecture in an attempt to improve adaptive instruction and feedback using a predictive model. We particularly investigate the effect of tactical breathing during a psychomotor task of golf putting. In general, learners are instructed to perform proper breathing while executing actions. However, it is not well understood that how the corresponding mechanisms of attentional control interact with the physiological factors as the learner progresses to the learning stage. In addition the instruction and feedback policy in a training system needs to deal with the changing attentional capacity in the learning stage. One of the advantages using an adaptive training system (e.g., Generalized Intelligent Framework for Training: GIFT) is to provide tailored feedback to the leaner. It is, thus, necessary to understand what influences skill development, and how physiological and cognitive processes work together to reinforce correct behaviors. Our study starts to answer such questions for psychomotor instruction within intelligent tutoring systems.

Keywords: Attention, Breathing, Psychomotor tasks, Intelligent Tutoring Systems (ITSs), Generalized Intelligent Framework for Tutoring (GIFT), High Level Behavior Representation Language (HERBAL), ACT-R/Φ

1 Introduction

Intelligent Tutoring Systems (ITSs) provide adaptive instruction to learners in a variety of cognitive domains (e.g., mathematics, physics, software programming). A new trend is to begin examining how ITSs might provide instruction in psychomotor domains (e.g., sports tasks, marksmanship, medical procedures) and measure learner behaviors directly to assess skill development [1, 2]. To support the adaptive instruction of psychomotor tasks, the US Army Research Laboratory is developing the Generalized Intelligent Framework for Tutoring (GIFT) with the goal of providing tools and methods to enable easy authoring, delivery, and evaluation of adaptive instruction in a wider variety of domains (e.g., cognitive, affective, psychomotor, and social/collaborative). This paper focuses on the challenges of providing adaptive instruction for psychomotor tasks and specifically addresses the question: Does tactical breathing in a psychomotor task influence skill development during adaptive instruction?

Tactical breathing is a specific breath-control technique used by individuals to perform a precision required psychomotor task under a stressful situation [3, 4]. Tactical breathing has been introduced to soldiers to control physiological responses and to stay in a zone where their performance is anticipated to be successful [5, p.39].

In this paper, we provide a new methodology to examine the functional relationship of cognitive and physiological factors. We use a cognitive modeling approach in an attempt to predict performance and to improve assessment methods, which can be applied to an adaptive instructional system. Our target task is golf-putting that requires precision. Particularly, we explore the functional relationship of tactical breathing and cognitive factors (i.e., attentional control) in terms of the learning stage. We believe that our effort combining a computational cognitive and physiological model will lead to better predictions of human performance, and can help us to make our assumptions explicit and to expose the veracity/fallacy of such assumptions. Finally, we describe how a model prediction can be used in GIFT in an attempt to generalize psychomotor tasks training, which can be useful to implement an adaptive and instructional training system.

2 The ABC of Psychomotor Tasks Training

In this section, we describe some background about the ABC (attention, breathing, and choking) of psychomotor tasks training. Supposed that you are hitting a golf ball. This action induces an effect that we may call the *movement effect* [6, p.137]. The movement effect includes several sub-actions: the motion of your club, the trajectory of the golf ball you hit, the landing point of the golf ball, etc. It is argued that an optimal attentional focus exists, and it helps to develop the expertise skill by facilitating the process of learning [7]. In general, the beginner golfer should focus on the movement of the golf club that is outside of the golfer's body. You might also recognize that many golfers focus on their body movements (hands, hips, legs, etc.).

How about breathing? Focusing on breathing can affect one's attentional resources during the performance. Tactical breathing can be a useful tool for the precision-required task, but it might influence one's attentional capacity. Then, what theories should we rely on in an attempt to instruct effectively? Are these useless for the beginner to focus on? Probably not. Then, when and what should the golfer (a novice or an expert) focus on?

2.1 Attention and Psychomotor Performance

Attentional control relates to learning and performance in psychomotor tasks. Wulf and her colleagues mention that the focus of attention not only affects performance but also facilitates learning/retention of psychomotor skills [6]. The focus of attention indicates that the learners direct attention either to body movements or the effects of movement. In general, the former is called *internal focus* and the latter is called *external focus*. A study reveals the benefits of learning by directing attention to other cues including task-relevant or task-irrelevant cues [8].

For example, in the task of learning to balance on a stabilometer, participants grouped into three conditions: (a) directing attention to the effects of the learners' movement effects (external cues, task-relevant), (b) directing attention to the learners' movements themselves (internal cues, task-relevant), and (c) directing attention to the attention-demanding secondary task (shadowing a story-telling: external cues, task-irrelevant). This study suggests that the learners are benefited from the attentional control instruction of directing attention to external cues that are the effects of the movement (task-relevant external cues). The underlying hypothesis is that adopting an external focus reduces conscious interference in the process that controls our movements and a consequence result. In this context, some scientists argue that it is effective for an expert golfers would perform better with less explicit knowledge about the task; not thinking about the movements (i.e., putting strokes) while executing the actions [9].

To address successful skill learning and performance, it is necessary to consider what mechanisms are responsible for the aforementioned phenomena in terms of the stages of learning (from a novice through to an expert). At the very beginning of the learning stage, the learners need to adopt internal focus to direct attention to coordination of various submovements that constitute the movement of a task skill. In the early stages, more attentional resources are required to execute the skill (i.e., step-by-step execution of the skill). On the other hand, in the later stage (i.e., the third stage), the task skill can be executed without excessive effort as related to attentional resources that is known as the autonomous stage in a theory (that is represented as the procedural stage in ACT-R).

We may also observe that a professional athlete performs much more poorly than expected when faced with an outcome-defining action, which is termed *choking under pressure*. For example, under highly stressful situations, a golfer, who is endeavoring to make the cut for the PGA tour, would perform more poorly than his/her skill level and capability. Performance degrades and performance gaps exist! Is it because attentional focus is shifted to task-irrelevant cues [10, 11]? Is it because there is increase in attention that is being paid to step-by-step execution of the task skill set rather than the proceduralized skill set in the later stage of learning [12, 13]? Can we, then, minimize the influence of stressors on performance by strategic practice of tactical breathing?

It has been reported that there is a functional relationship between attentional control and psychomotor performance [14]. Particularly, skill levels (from a novice to an expert) are related to attentional resources (i.e., step-by-step execution of skill components and proceduralized performance). In addition, it is reported that a physiological change (e.g., breathing, heart rate) is related to psychomotor performance under stressful situations [5]. It can be, therefore, argued that physiological and cognitive factors are interrelated with psychomotor performance, and, thus, an advanced understanding of such factors is highly necessary to improve instruction and feedback.

There are two competing theories. The different stages of learning would require different attentional resources. That is, in the earlier stage, if the task skill execution depends on retrieval of memory items in declarative memory, a stress factor would create the potential distraction to shift attentional focus to task-irrelevant cues such as worries, a process known as distraction theories [11]. Another relevant theory applies to explicit monitoring of task skill execution. In the middle and later stages, task skills are proceduralized, indicating execution of task skill is largely unattended without the service of working memory, like the skilled typist. In this explicit monitoring theory, a stress factor raises anxiety about performing correctly, which causes the reversion of attentional focus to step-by-step control of skill processes [12, 13]. Thus, this theory can explain performance failure in the later stage.

Beilock and Carr [15] pointed out that the aforementioned theories have been seemingly considered to be mutually exclusive but should, in fact, be considered to be complimentary. This complimentary understanding is possible when we consider the three stages of learning and retention [16]. That is, under the distraction theory, task skills reside in the early stage and rely on declarative memory item retrieval, and under explicit monitoring theory, task skills reside in the later stages and rely on production rules. The aforementioned distraction and explicit monitoring theories can partly account for the phenomenon, how are physiological factors interrelated with attention resources in terms of skill learning stages.

2.2 Physiological Factors and Psychomotor Performance

Neumann and Thomas [3, 4] investigated measures of cardiac and respiratory activities when individuals at different levels of skill developments during the golf putting task. Compared to a novice golfer, the expert golfers showed a pronounced phasic deceleration in heart rate immediately prior to the putt, and greater heart rate variability in the very low frequency band, and a greater tendency to show a respiratory pattern of exhaling immediately prior to the putt [3]. And, in a follow up investigation of Neumann and Thomas, participants performed the putting task to measure both cardiac and respiratory activity under with or without attentional focus instructions [4]. The results show that the experienced and elite golfers showed better performance and reduced heart rate (HR), greater heart rate variability (HRV), pronounced HR deceleration prior to the putt, and a greater tendency to exhale prior to the putt, compared to novice golfers. This study shows a relationship between psychomotor performance, physiological factors, and the skill level.

It is reported that a range of heart rates is related to psychomotor skill performance—i.e., around 115 beats per minute (bpm), fine motor skills are beginning to deteriorate, and complex psychomotor skills are degraded around 145 bpm, and gross motor skills (e.g., running) start to break down above 175 bpm [5, p.31]. As a training regimen, a tactical breathing method is used to address psychomotor performance under pressure [5], and, it also has been reported that a breathing technique can lower blood pressure [17]. Furthermore, there is a report that psychological performance training including tactical breathing help to manage stress; i.e., tactical breathing and mental imagery can mitigate negative effects of stress for police officers [18], and stress management training with tactical breathing is effective in reducing stress in soldiers [19]. As a technique to delink memory from a physiological arousal, soldiers are trained to do tactical breathing to lower their heart rates.

One of the major causes of choking is self-focused attention [6]. It is very curious what the individuals focus on under time stress; do they control their movements (i.e., internal focus)? If so, instead of internal focus, it might be desirable to direct attention to external cues so that it can prevent (or reduce) choking. If we view tactical breathing as a task-irrelevant internal cue, a novice would suffer from performance degradation by tactical breathing that would demand additional attention, but, in the meantime, it could help the expert to better deal with choking. It is still necessary to further investigate the functional relationship between the cognitive factor (attentional control) and the physiological factors (breathing and heart rate variability) in terms of the skill level. Tactical breathing can be considered as a means to control attentional focus. Thus, if you use tactical breathing, you may have better performance by controlling your attention (breathing as an attentional focus training method).

3 The Cognitive Model

We seek to implement a series of computational models that can summarize the relationship between cognitive and physiological aspects for psychomotor tasks. We chose to use ACT-R [20] to implement a cognitive model since it is one of the widely used cognitive architectures. Also, we use a high-level behavior representation language (Herbal) [21] to organize the task knowledge of a golf-putting task.

The task knowledge used in this study adopts the instruction developed in the previous study by Beilock and her colleagues [14]. Knowledge components for a typical golf putting can be separated into (a) assessment, and (b) execution steps. For the assessment step, a golfer gathers information to judge the line of the ball, the grain of the turf, and distance/angle to the hole. Then, a golfer sequentially executes a series of mechanical actions: (a) position the ball between the center of the feet, (b) align shoulders, hips, knees, and feet, (c) check postures of grip, standing, arms, hands, and head, (d) check weight distribution, (e) stroke, (f) keep appropriate postures after stroke. As you see, the putting task requires cognitive resources during the action.

3.1 High Level Behavior Representation Language: Herbal

Herbal supports ontological representation of the task knowledge based on the Problem Space Computational Model [PSCM, 22]. A computational model can be created by editing Herbal's classes with an Eclipse plug-in or directly in XML. Developers can directly modify the Herbal XML code, and Herbal compiles the XML representation into low-level rule-based representations that can be run in several architectures such as Soar, Jess, and ACT-R. A recent addition to Herbal provides a capability to efficiently support ontological representation of task knowledge and to automatically generate a series of ACT-R models [23]. Table 1 shows the XML structure of the declarative memory elements.

Table 1. The XML structure of the declarative memory element of "Assessment".

```
<declarativememory name='Assessment'>
  <rationale>
    <what></what>
    <how></how>
    <why></why>
  </rationale>
  <parent name='Putting'/>
  <firstchild name='JudgeLineOfBall'/>
  <nextsibling name='Execution'/>
  <action name='none'/>
  <perceptualmotor name='none'/>
  <chunktype name='none'/>
  <key name='none' isString='false'/>
  <nextperceptualmotor name='none'/>
  <prerequest name='none'/>
</declarativememory>
```

In our study, Herbal helps to clarify the task knowledge structure of the golf-putting task as shown in Figure 1. In Herbal, the topmost entity, the agent, operates within a problem space which contains a global goal. Each problem space is a collection of several subproblem spaces with a local goal that serves for the topmost problem space. For the golf-putting task, we created the agent named `golfPutting` with a problem space of `Putt`.

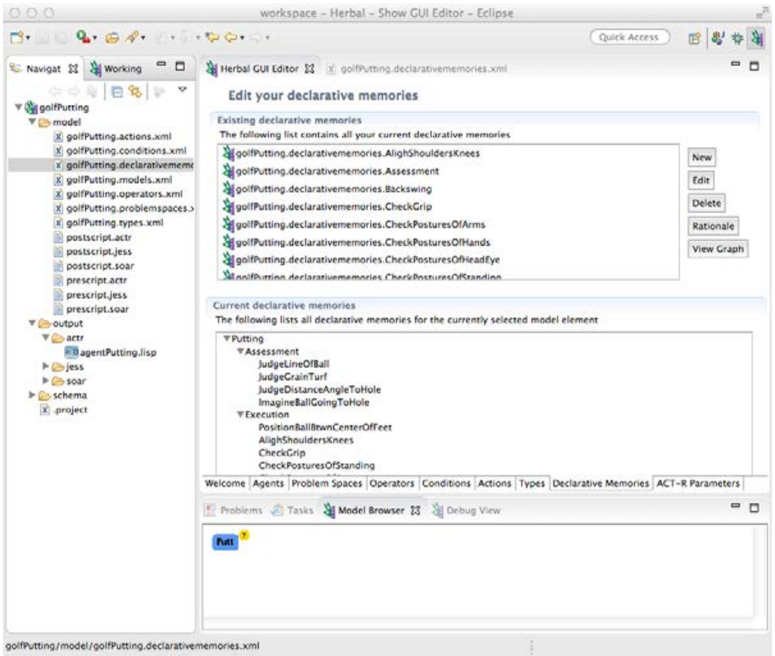

Fig. 1. The structure of the golf-putting task in the Herbal GUI environment.

3.2 The ACT-R Model of Putting

We created a series of ACT-R models that represent the golf-putting performance—the time to complete a putting task in terms of the varying skill levels (e.g., a novice, a journeyman, and an expert). The ACT-R theory assumes distinctive memory systems of declarative and procedural memory. Declarative knowledge is factual or experiential. One of the declarative memory item is "Judge Line of the Ball", as shown below. It is associated with assessment to gather information before the stroke—it has a parent of `GatherInfo` in the ontological hierarchy. Also, it has a next sibling subtask, `JudgeGrainTurf`.

```
(JudgeLineOfBall ISA task-DMs Element_Name JudgeLineOfBall
Parent_Name GatherInfo Next_Sibling_Name JudgeGrainTurf is-
String false Action_Name none Post JudgeGrainTurf)
```

Procedural knowledge in the model is goal-directed. The following two productions show how goals are satisfied in the condition statement. The first production is to start the putting task by checking the goal buffer if the slot values are doing a putt and ready to retrieve the next sibling subtask that is to check grip. The second production also shows a goal-directed behavior of checking the standing posture.

```
(P Start
 =goal> isa  dm
      Start  Putting
      state  nil
==>
 =goal> state  Putting
 +retrieval>  isa  task-dms
      element_name CheckGrip
      !output! (none)
)

(P CheckPosturesOfStanding
 =goal> isa  dm
      state  CheckPosturesOfStanding
 =retrieval>  isa  task-dms
      element_name CheckPosturesOfStanding
      post =post
==>
 =goal> state  CheckPosturesOfArms
 +retrieval>  isa  task-dms
      element_name =post
      !output! (none)
)
```

The novice model consists of 22 declarative memory elements and 25 production rules to produce behavior. Accordingly, for the journeyman, the total number of declarative memory items is 22 and the total number of production rules is 22. The expert model uses the same number of declarative memory that the journeyman and the novice model use, but uses 20 production rules to produce behavior; that is, it takes less explicit, goal-directed, steps for experts to complete the putt problem-space. In this manner, we can present levels of expertise.

Based on the task knowledge structure, the ACT-R model predicts learning performance—the time to complete the task in terms of the three stages of learning. In the first stage, the model learns task knowledge from instructions. It is an initial encoding of facts about task knowledge. Then, in the second stage (declarative + procedural), the acquired task knowledge is interpreted to produce behavior. Through a mechanism called knowledge compilation (or production compilation), the acquired task knowledge is converted to a procedural form with practice. After knowledge compilation, further tuning of task knowledge occurs in the third stage, producing a speedup of the knowledge application process. This is referred to as the procedural stage.

Figure 2 shows the time decreasing both by the skill level and by practice trials. The ACT-R model's learning is dependent on the activation mechanism that controls the probability and time to retrieve knowledge from declarative memory and the production compilation mechanism that is in charge of a production rule learning.

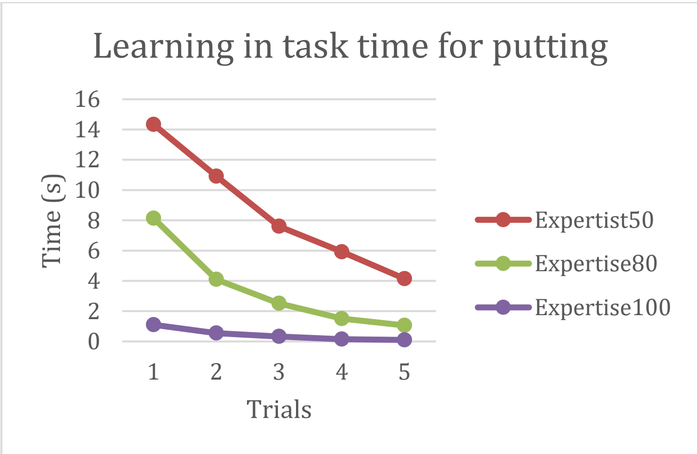

Fig. 2. Learning curves by the different skill level.

3.3 Computational Explorations of Breathing using ACT-R/Φ

The ACT-R/Φ architecture extends the ACT-R cognitive architecture with the HumMod physiological model and simulation system [24-26]. Physiological variables within the HumMod system modulate certain cognitive parameters so that changes in physiology subsymbolically affect memory—e.g., stress variables such as epinephrine modulate the ability for a model to successfully retrieve the correct declarative memory. Even though ties between stress-related variables and cognitive parameters have been previously explored [25, 26], modulations of physiological and cognitive processes due to tactical breathing have not previously been studied using cognitive architectures.

Given that tactical breathing modulates physiological systems that affect stress systems, these mechanisms are somewhat already present within the ACT-R/Φ architecture. Indeed, respiratory-related sensory mechanisms (e.g., those related to tidal volume and pulmonary stretch reflexes) have been shown to modulate sympathetic and parasympathetic nervous systems activity [27, 28]. Deep slow breathing (i.e., similar to the breathing exhibited during tactical breathing) enhances parasympathetic activation and tends to inhibit sympathetic activity [28].

Tactical breathing produces a calming effect that can, in a stressful situation, allow one to better focus on current goals and reduce stress (e.g., see [e.g., 19, for a study on related techniques used to reduce stress during a battle simulation] for a study on related techniques used to reduce stress during a battle simulation.) Following the respiratory effects on peripheral release of catecholamines [29], one can trace potential effects on cognitive abilities; the aforementioned catecholamines modulate behavioral arousal (including through indirect mechanisms via afferents that modulate the locus coeuruleus (LC)-noradrenergic system). Previous work on LC-noradrenergic (arousal) modulation of behavior [30] provides some clarity on a way to connect known respiratory effects on autonomic activity to cognitive processes and behavioral effects.

Figure 3 gives a high-level picture of the effects of arousal on memory systems in ACT-R/Φ. With this representation, low arousal (e.g., being tired) results in an overall lowering of all subsymbolic properties of memory elements. The properties all increase non-linearly as the arousal representation increases. In ACT-R/Φ, arousal is determined using cortisol, epinephrine, corticotrophin releasing hormone (CRH). Equation 1 reflects the involvement of these variables in arousal.

$$Arousal = f(cort) * [\alpha * g(crh) + \beta * h(epi)] \qquad \text{Eq. (1)}$$

The equation reflects evidence that cortisol seems to serve more of a multiplicative than additive role in memory-based arousal due to the LC system [31, 32]. In Equation 1, α and β are parameters that determine the slope of the linear relation between deviation from the normal physiological state; $f(cort)$, $g(crh)$, and $h(epi)$ are a function of the change in cortisol, CRH, and epinephrine (respectively) from the baseline state. It is important to note that the non-linearity displayed in Figure 3 (within the "arousal vs x" graphs) is accomplished intrinsically within the physiology system: physiological variables involved in the stress system change non-linearly via interactions with other variables over-time.

To accomplish tactical breathing within ACT-R/Φ, the physiology system (i.e., HumMod) is made to breath with certain parameters (e.g., tidal volume). The Integrative HumMod provides built-in mechanisms to change and track breathing over simulated time. This direct change in the physiological system, coupled with the existing arousal representation, allows the use of an Herbal compiled ACT-R model in the ACT-R/Φ architecture. Only a few parameters must be added to the model to allow it to use the physiological representations.

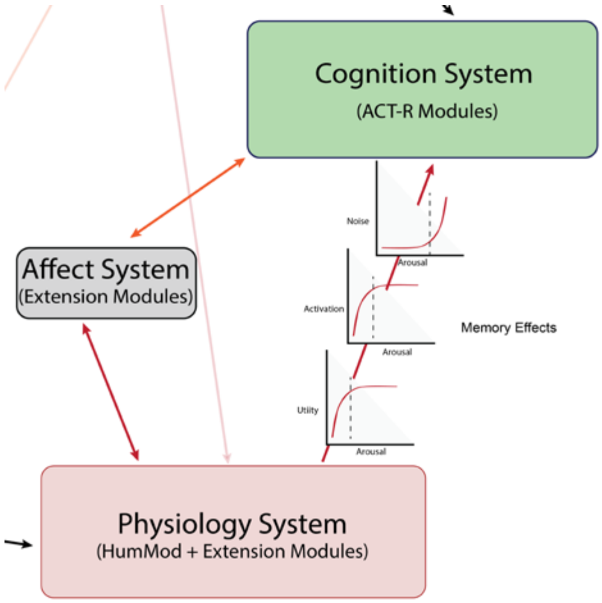

Fig. 3. A high-level picture of the memory effects of arousal between the physiology and cognition systems in ACT-R/Φ.

4 Discussion and Conclusions

In this paper, we presented the importance of tactical breathing in psychomotor tasks, and the methodology of integrating a cognitive model with physiological modulations. We suggested a convincing solution to implement the ACT-R model that can be efficiently generated by Herbal in an attempt to represent a real world sports task, a golf-putting. The major advantage of such a cognitive model provides cognitive process of learning and skill development, which is useful to improve an intelligent tutoring system. Our attempts in this paper can persuade researchers to incorporate computational model predictions to improve skill assessment strategies in the development of adaptive instruction and feedback. The following paragraphs describe future directions illuminated by the current study.

4.1 Toward an adaptive feedback and instruction in GIFT

Establishing a predictive model of tactical breathing in GIFT requires some architectural considerations. With GIFT being a domain-agnostic framework, a concept must be established in a domain's ontological representation of the things to be assessed, as configured through a domain knowledge file (DKF). The DKF is used to associate a concept, such as tactical breathing, with a designated Java condition class designed to inform state assessments. The condition class is used to configure the model parameters and thresholds that will be used at training runtime.

The output of those models are encoded in a domain module message, and sent to GIFT's learner module to update the trainee's state as it associates with the event they are experiencing. This trainee state is then communicated to the pedagogical module for determining how best to manage the trainee from a pedagogical standpoint. With a model in place monitoring tactical breathing application, specific instructional strategies and tactics must be created for use when the model designates an individual as needing assistance. These interventions must be grounded in the concept they are intended to correct/reinforce, and should be based on instructional design and expert opinion. If someone is not breathing in a fashion congruent to tactical application, what intervention can be triggered to correct that individual's behavior? These elements of pedagogy and content must be established upfront for a closed-loop trainer that can focus application on tactical breathing procedures.

4.2 Lessons Learned from Existing Breathing Data

An analysis on the existing breathing data was to establish models for incorporation in a closed-loop ITS. The breathing data corresponds with an established fundamental of marksmanship procedures, as captured in the U.S. Army FM 3-22.9 [33]. The first analysis approach was associated with the behavioral application of breathing while executing a marksmanship grouping exercise. The goal was to investigate the utility of a generalized model of breathing based on expert application.

Data was collected across eight experts. With a large corpus of behavioral measures, we constructed models through the following procedure: (a) we computed the derivative for all associated values captured in the raw breathing wave form, (b) we established a time-window around the shot event to parse out data values (i.e., looking at breathing 1.5 seconds before the shot to 0.5 seconds following), (c) we calculated the Area Under the Curve (AUC) for that configured time-window, and (d) we performed a cross-fold validation procedure on expert data through an n-1 approach [34]. Outcomes of this analysis demonstrated a generalizable model of breathing application during the marksmanship task. The resulting AUC descriptive models were integrated in GIFT for assessment criteria during a training event. Then, the system can identify erroneous breathing application based on a comparison of trainee data with expert model values, with an associated 2-standard deviation threshold being defined for classifying improper breathing technique. These models can then be used to provide feedback contents and to instruct proper breathing techniques.

Based on this previous investigation on marksmanship, the cognitive modeling approach presented in this paper can provide much more generalized behavior regularity with predictions for other psychomotor tasks domains (e.g. sports, medical practices, and other military related tasks), which can be used for skill assessment and adaptive instructions. Also, a greater advantage can be expected to provide a stress resistant training by a computational understanding of cognitive and physiological characteristics (e.g., ACT-R/Φ). The use of stress management training including tactical breathing is a promising method to effectively reduce stress to improve psychomotor performance. Furthermore, this attempt provides a step toward an intelligent psychomotor tasks tutoring beyond the desktop environment.

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