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Subjective Cognitive Effort:
A Model of States, Traits and Time

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Abstract

Self-regulation theories were used to develop a dynamic model of the determinants of subjective cognitive effort. The authors assessed the roles of malleable states and stable individual differences. Subjective cognitive effort and perceived difficulty were measured whilst individuals performed an Air Traffic Control task. As expected, conscientiousness moderated the effort trajectory. Individuals with high conscientiousness maintained subjective cognitive effort at high levels for longer than their counterparts. There were also individual differences in reactions to perceptions of task difficulty. The intra-individual relationship between perceived difficulty and subjective cognitive effort was stronger for individuals with low ability or low conscientiousness than their counterparts. A follow-up study showed that the measures of perceived difficulty and subjective cognitive effort were sensitive to a task difficulty manipulation; and that the relationship between perceived difficulty and subjective cognitive effort held after controlling for self-set goal level. These findings contribute to the self-regulation literature by identifying factors that influence changes in subjective cognitive effort during skill acquisition.

Subjective Cognitive Effort:

A Model of States, Traits and Time

Effort plays a central role in motivation theory. Motivation theories treat effort as a dynamic construct that changes within individuals in response to individual and environmental factors (Bandura, 1986; Kanfer, Ackerman, & Heggstad, 1996; Locke, 1968; Vroom, 1964). Empirical studies, however, have tended to treat effort as static rather than dynamic (Fried & Slowik, 2004). There is growing awareness of the need to match the level of analysis at which constructs are operationalized to the level of analysis that is inherent in theory (Kozlowski & Klein, 2000). There have been repeated calls for the study of motivational processes at the intra-individual level (Cervone, 2004; C. Fisher, 2002; Mischel & Shoda, 1998; Vancouver, 2005). Few researchers have taken up this call. Between 1997-2007, 180 studies were published in the *Journal of Applied Psychology* using motivationally-relevant keywords (employee/work motivation/effort, self-regulation, self-efficacy, goals/goal-setting). Only ten analyzed relationships among time-varying constructs at the intra-individual level. The majority of these examined relationships involving various combinations of self-efficacy, feedback, goal regulation and performance (DeShon, Kozlowski, Schmidt, Milner, & Wiechmann, 2004; Donovan & Williams, 2003; Ilies & Judge, 2005; Vancouver & Kendall, 2006; Vancouver, Thompson, Tischner, & Putka, 2002; Vancouver, Thompson, & Williams, 2001; Wanberg, Glomb, Song, & Sorenson, 2005; Yeo & Neal, 2006). Only three studies measured effort (DeShon et al., 2004; Smillie, Yeo, Furnham, & Jackson, 2006; Yeo & Neal, 2004). None of these examined the factors that produce changes in effort within individuals over time.

Thus, although empirical studies are starting to examine intra-individual relationships among motivationally-relevant constructs, this work is still in its infancy. In this paper, we examine intra-individual differences in subjective cognitive effort as a function of practice and perceptions of difficulty; and how these dynamic self-regulatory patterns can depend on inter-individual differences in cognitive ability and conscientiousness.

Cognitive Effort Allocation

Effort can be physical and cognitive (Kanfer, 1992). We focus on cognitive effort. Theories of information processing treat cognitive effort as a hypothetical construct. They conceptualize cognitive effort as a limited capacity resource that affects the speed of information processing (Humphreys & Revelle, 1984; Kahneman, 1973). If a task is “resource limited”, then performance will improve if more cognitive effort is allocated to that task (Kanfer, 1987; Norman & Bobrow, 1975). Within the work motivation literature, cognitive effort is also frequently treated as a hypothetical construct (Ambrose & Kulik, 1999; Pinder, 1998). Consequently, motivation researchers have often used tasks where effort is thought to be the primary determinant of performance, and have drawn inferences regarding effort from the way that individuals respond to different motivational predictors or interventions (Ambrose & Kulik, 1999; Kanfer, 1992). Although cognitive effort may be a hypothetical construct, it is accompanied by a subjective state that people have introspective access to (Humphreys & Revelle, 1984; Locke & Latham, 2004). The subjective experience of effort is one of ‘trying hard’ (Porter & Lawler, 1968; Vroom, 1964).

Motivation theories assume that cognitive effort allocation decisions are influenced by distal and proximal processes. Distal processes are responsible for choice behaviors. They guide the establishment of intentions and choices between alternative courses of action by influencing the desired performance level and the proportion of total resource capacity that will be devoted to different tasks (Carver & Scheier, 1998; Kanfer, 1990; Karoly, 1993). The distal component of the motivational process is also referred to as the goal-setting phase (e.g. Karoly, 1993). The choices that are made in this phase are influenced by factors such as valence, instrumentality and self-efficacy (DeShon & Gillespie, 2005; Kanfer & Heggestad, 1999; Vroom, 1964).

Proximal processes are responsible for the allocation of cognitive effort to on-task, off-task and self-regulatory processes during task engagement (Kahneman, 1973; Kanfer, 1990; Karoly, 1993). Self-regulation theorists describe these processes in terms of a feedback control mechanism (Brehm & Self, 1989; Carver & Scheier, 1998; Karoly, 1993; Vancouver, 2005). Individuals are assumed to

adjust their cognitive effort in response to changes in the amount of cognitive effort that is required to achieve their desired performance level. The proximal component of the motivational process is also referred to as the goal-striving phase (e.g. Karoly, 1993). Proximal motivational processes are the focus of the current paper.

We examined how subjective cognitive effort changes in response to changes in the amount of effort that is required by the task, and how stable individual differences influence this process. Skill acquisition tasks are useful for examining the dynamics of proximal motivational processes, because the amount of cognitive effort that is required should decrease as the individual becomes more skilled (Ackerman, Kanfer, & Goff, 1995). We examined general cognitive ability because it is thought to reflect differences in total resource capacity (Kanfer & Ackerman, 1989) and conscientiousness because it reflects individual differences in effort allocation (Kanfer, 1990).

Determinants of Subjective Cognitive Effort

Practice & Perceived Difficulty

One potential determinant of subject cognitive effort is practice. Skill acquisition theories assume that the amount of cognitive effort required to perform a task decreases with skill, and that skill requires practice (Anderson, 1982; Fitts & Posner, 1967; Logan, 1988). If a task requires consistent information processing, then practice produces a transition from controlled to automatic processing (Shiffrin & Schneider, 1977). The rate at which performance improves during skill acquisition is described by the Power Law of Practice (Newell & Rosenbloom, 1981). There are a number of variables that influence the rate of skill acquisition, including ability and task difficulty. If the amount of effort required to perform the task decreases, then self-regulation theories predict that individuals will reduce the amount of cognitive effort that they allocate to the task (Carver & Scheier, 1998; Kanfer & Ackerman, 1989).

Hypothesis 1: Subjective cognitive effort will decline as a function of practice, producing a negative growth trajectory.

A second potential determinant of subjective cognitive effort is perceived difficulty. Self-regulation theories suggest that individuals increase their allocation of cognitive effort towards on-task activities when tasks become more difficult, due to a discrepancy between current and desired levels of performance (Brehm & Self, 1989; Carver & Scheier, 1998; Kanfer & Ackerman, 1989; Karoly, 1993; Vancouver, 2005). Goal setting research provides indirect support for this relationship. Behavioral indicators of cognitive effort, such as time on task, have responded positively to increases in goal difficulty (Bandura & Cervone, 1986; Weingart, 1992). Maynard and Hakel (1997) demonstrated a positive association between perceived difficulty and subjective motivation at the inter-individual level. Other factors may influence this relationship, such as efficacy beliefs, goal level, and task commitment. For example, if the required amount of effort exceeds the maximum amount of effort that an individual is prepared to expend, or an individual has lost confidence, then she may give up (Bandura, 1997; Brehm & Self, 1989). However, previous studies examining motivation via both physiological and self-report measures suggest that, in the laboratory at least, it takes extreme manipulations of task difficulty before a participant withdraws effort (Obrist et al., 1978; Wright, 1984; Wright, Contrada, & Patane, 1986). We use an air traffic control (ATC) simulation, on which performance has been shown to be difficult yet achievable (Kanfer et al., 1996; Yeo & Neal, 2004, 2006). Therefore, we expected to find a positive relationship between perceived difficulty and subjective cognitive effort within individuals.

The predictions described above represent a fairly straightforward application of self-regulation theories. What is less obvious is how perceived difficulty should interact with practice. Is the relationship between difficulty and cognitive effort static or dynamic? We draw on the self-regulation literature to generate a hypothesis. At the intra-individual level, perceived difficulty acts as a self-regulatory prompt - perceptions of difficulty cue individuals with regard to how much cognitive effort they need to allocate (Carver & Scheier, 1998; Kanfer & Ackerman, 1989). When individuals begin learning a task, however, they may not know what the optimal amount of effort is given a particular difficulty level. As they become more skilled, they should get better at regulating

their cognitive effort. Kanfer and Heggstad (1997) argue that self-regulatory competencies can be improved through training because they are malleable skills. Thus, the intra-individual relationship between perceived difficulty and subjective cognitive effort should strengthen over time.

Hypothesis 2a: At the intra-individual level of analysis, increases in perceived difficulty will be positively related to increases in subjective cognitive effort.

Hypothesis 2b: At the intra-individual level of analysis, the relationship between perceived difficulty and subjective cognitive effort will strengthen throughout practice.

Cognitive Ability

Principles from information-processing and self-regulation theories (Humphreys & Revelle, 1984; Kanfer & Ackerman, 1989) predict that cognitive ability should interact with practice and perceived difficulty. If the amount of cognitive effort that individuals allocate to a task decreases as they become more skilled, the rate of change in cognitive effort should depend on the rate of skill acquisition. Cognitive ability has been shown to predict individual differences in the rate of skill acquisition (e.g. Deadrick, Bennett, & Russell, 1997). If high ability individuals learn faster than low ability individuals, then subjective cognitive effort should decline at a faster rate.

Turning next to perceived difficulty, self-regulation theories (Carver & Scheier, 1998; Karoly, 1993) suggest that individuals with different levels of cognitive ability may react to changes in task difficulty in different ways. High ability individuals have a larger pool of cognitive resources than their counterparts, and require a smaller proportion to achieve the same performance outcome. When high ability individuals perceive an increase in difficulty, the corresponding increase in cognitive effort should be proportionately smaller than for their counterparts. Low ability individuals need to make larger resource adjustments (proportionately), to achieve the same outcome as their counterparts. We expect that the relationship between perceived difficulty and subjective cognitive effort will be strongest for individuals with low, rather than high ability.

Hypothesis 3a: Cognitive ability will moderate the subjective cognitive effort trajectory.

Subjective cognitive effort will decline faster for individuals with high levels of cognitive ability than for individuals with low levels of cognitive ability.

Hypothesis 3b: There will be a cross-level interaction between perceived difficulty and cognitive ability. The intra-individual relationship between perceived difficulty and subjective cognitive effort will be stronger for individuals with low cognitive ability than for individuals with high cognitive ability.

Conscientiousness

Conscientiousness may also moderate the effects of practice and perceived difficulty on subjective cognitive effort. There are two mechanisms by which conscientiousness may produce individual differences in cognitive effort trajectories. First, conscientiousness is a volitional trait. Highly conscientious individuals choose to work harder and persevere longer than their counterparts (Barrick, Mount, & Strauss, 1993). Highly conscientiousness individuals should show greater persistence by maintaining high cognitive effort over time, despite the fact that the required amount of effort decreases as they become more skilled. Second, conscientiousness may influence skill acquisition rates. Some researchers argue that conscientiousness can have a negative effect on performance in time pressured tasks (Tett, Jackson, Rothstein, & Reddon, 1999) or in learning contexts (Colquitt, LePine, & Noe, 2000). Yeo and Neal (2004) showed that individuals with high conscientiousness learnt an ATC task which involved time pressure, at a slower rate than their counterparts. Thus, individuals with high conscientiousness may maintain high levels of subjective cognitive effort, because their rate of skill acquisition is slower than their counterparts.

The intra-individual relationship between perceived difficulty and subjective cognitive effort should also be moderated by conscientiousness. In this case, it is the volitional properties of conscientiousness that should produce the interaction. If high conscientiousness is related to hard work and perseverance (Barrick et al., 1993), then highly conscientious people should react less to changes in difficulty than their counterparts. Highly conscientiousness individuals should expend

high levels of cognitive effort relatively consistently, regardless of task difficulty. Less conscientious individuals should report more varied levels of cognitive effort, only expending high levels when necessary.

Hypothesis 4a: There will be a cross-level main effect of conscientiousness on subjective cognitive effort, such that individuals with high levels of conscientiousness will report higher levels of subjective cognitive effort than individuals with low levels of conscientiousness.

Hypothesis 4b: Conscientiousness will moderate the subjective cognitive effort trajectory. Subjective cognitive effort will decline slower for individuals who report high levels of conscientiousness than for individuals who report low levels of conscientiousness.

Hypothesis 4c: There will be a cross-level interaction between perceived difficulty and conscientiousness, such that the intra-individual relationship between perceived difficulty and subjective cognitive effort will be stronger for individuals with low conscientiousness than for individuals with high conscientiousness.

Study 1

Method

Experimental Task

This study used the conflict resolution task from the ATC-lab suite (Loft, Hill, Neal, Humphreys, & Yeo, 2004). Simulated ATC tasks are useful because they are novel and cognitively complex, induce variability in cognitive effort throughout skill acquisition, and allow individuals to improve their performance within a short space of time (Ackerman et al., 1995; Yeo & Neal, 2004, 2006). The participant's objective in this task is to ensure aircraft reach their destination safely. Specifically, participants must ensure that all aircraft remain separated by at least five kilometres, and do so by controlling the speed of the aircraft. To change the speed, participants select the aircraft with the left mouse button, activate the speed menu by right clicking and select the desired speed ("minimum", "medium" or "maximum"). Each trial had eight aircraft on the screen at any

one point in time. Fourteen, five-minute trials were created. The first was treated as a familiarization trial and was excluded from analyses.

Measures

Cognitive effort and difficulty. These measures were based on Yeo and Neal (2004). The task froze five times during each trial (60 seconds apart, starting at 30 seconds), and participants were asked to rate the questions: "How difficult did you find the task just before the screen froze?" and "How hard were you trying just before the screen froze?" Participants responded on an 11-point scale ranked from 0 (*not at all*) to 10 (*extremely difficult/extremely hard*). Our measure of subjective cognitive effort assesses intensity at a specific point in time (Porter & Lawler, 1968).

The multiple ratings were averaged within each trial to calculate a single score for subjective cognitive effort and perceived difficulty for each participant on each trial¹. The internal consistencies were calculated for the five raw scores within each of the 13 trials. These estimates ranged from $\alpha = .91$ (Trial 1) to $\alpha = .95$ (Trials 3 and 4) ($M = .94$, $SD = .01$) for subjective cognitive effort and from $\alpha = .86$ (Trial 1) to $\alpha = .94$ (Trial 4) ($M = .90$, $SD = .02$) for perceived difficulty.

Cognitive ability. Raven's Advanced Progressive Matrices (Raven, 1990) were used to measure cognitive ability. This test is designed for the top 25% of the population, and is thus suitable for undergraduate university students (Bors & Stokes, 1998). Reliabilities range from .70 to .90 (Murphy & Davidshofer, 1998). The reliability for the current sample was .87.

Conscientiousness. The Revised NEO Personality Inventory (NEO-PIR) (Costa & McCrae, 1992) was used to measure Conscientiousness. This construct is measured with 48 items. An example item is: "I strive to achieve all I can" Responses are measured on a 5-point scale ranging from 1 (*strongly disagree or definitely false*) to 5 (*strongly agree or definitely true*). Reliabilities range from .76 to .86 (Leong & Dollinger, 1990) and research supports this scale's construct validity (Piedmont & Weinstein, 1993). The reliability of this scale in the current study was $\alpha = .93$.

¹ An anonymous reviewer noted that averaging across these within-trial measurement occasions partially confounds the causal order and therefore might influence the results. A 3-level analysis was conducted in which perceived difficulty and effort were assessed at the within-trial level, in which the five repeated measurements of perceived difficulty are paired with the corresponding five repeated measurements of effort (and thus no overlap). The findings from this model were the same as those for the 2-level analysis in which perceived difficulty and effort were aggregated to the trial level.

Task performance. Task performance was included as an outcome measure to check the validity of the self-report measure of cognitive effort. Participants accrued 100 penalty points per aircraft that violated separation, and a further three penalty points per second for each aircraft, until the separation standard was re-established. Lower scores represented better task performance.

Practice variables. The hypotheses involving practice were assessed by modeling the subjective cognitive effort growth trajectory with orthogonal linear and quadratic polynomial contrasts (for the weights, see R. Fisher & Yates, 1974). Orthogonal contrasts avoid multicollinearity (Ployhart, Holtz, & Bliese, 2002). The intercept represents subjective cognitive effort halfway through practice. The coefficient values produced are different to those resulting from standard polynomial values, however both methods produce the same graphs (Ployhart et al., 2002) which are used for interpretation. The intra-individual interaction parameters among practice and perceived difficulty were created by grand-mean centering perceived difficulty and computing their cross-products.

Participants & Procedure

One hundred undergraduate psychology students participated in this study in return for course credit. One participant's data were incomplete due to technical difficulties so the final sample size was 99. There were 60 females and 39 males. The mean age was 21.25 years ($SD = 5.30$). This study was conducted in three hour sessions with a maximum of six participants in each. Participants completed the cognitive ability and conscientiousness measures in a classroom. Next, they completed the ATC task in a computer laboratory. Instructions were provided in audio-visual mode. Participants completed 14 five-minute trials, with 20-second breaks. During each trial, the task froze five times and participants were asked to complete self-report measures of perceived difficulty and subjective cognitive effort. The ATC task took approximately 75 minutes to complete.

Analysis Strategy

Analyses were conducted using the HMLM option within Hierarchical Linear Modeling (Bryk & Raudenbush, 1992). The dependent variable was the subjective cognitive effort score across each trial, for each individual. The level 1 predictors were perceived difficulty, the trajectory parameters

and their interactions with difficulty. The level 2 predictors were cognitive ability and conscientiousness. Perceived difficulty and the level 2 predictors were grand-mean centered.

We followed Bliese and Ployhart's (2002) guidelines for growth curve modeling. Step 1 involves running a model with no predictor variables in order to estimate the intra-class correlation coefficient (ICC1). Step 2 involves testing the growth trajectory parameters as fixed effects. At Step 3, deviance tests assess whether these trajectories vary significantly across people.

Perceived difficulty is also a level 1 variable, but unlike the trajectory variables, it is a stochastic time-varying variable because it can take on different values at any one time point (Fitzmaurice, Laird, & Ware, 2004). Bliese and Ployhart (2002) do not incorporate this type of variable into their guidelines. We argue that stochastic time-varying variables should be assessed *after* the trajectory variables (i.e. at Step 4). This is because introduction of the trajectory variables can increase the amount of level 2 variance around the intercept. The inter-individual variability in the trajectory variable is often higher than assumed by the sampling model, and thus the intercept variance tends to be overestimated (Hox, 2002; Snijders & Bosker, 1994). Hox's (2002) advice is to use the level 1 variance component from the intercept-only model (Step 1) as the baseline for level 1 effect sizes; and the level 2 variance components from the model that includes all appropriate trajectory variables and their random effects (Step 3) as the baseline for level 2 effect sizes. Given that stochastic time-varying variables can explain variance at level 2 as well as at level 1, they should be introduced after the growth curve model is established².

Step 5 assesses alternative level 1 error structures such as autocorrelation. If one is identified, Bliese and Ployhart (2002) recommend that previous steps be repeated to ensure that the results hold. They did not discuss the estimation of effect sizes, however, we advise that effect sizes should be based on models with the identified error structure. At Step 6, level 2 variables are specified as predictors of the intercept and slope parameters consistent with the Hypotheses.

² The HMLM option within the HLM program does not allow stochastic time-varying variables to be random because this would create estimation problems when also modelling alternative error structures. The significance of the cross-level interaction between perceived difficulty and ability/conscientiousness can still be tested with a t-test. However, the user can only examine how much variance the cross-level interaction accounts for around the intercept and trajectory slopes, and not around the perceived difficulty slope because it will not have a random component.

In line with previous research using multilevel analyses (Smillie et al., 2006; Yeo & Neal, 2004), we set the criterion for cross-level interaction effects at the $p < .10$ level and for other effects at $p < .05$. This was done because the power required to detect cross-level interactions in multilevel research is frequently low, due to reductions in parameter reliability (Snijders & Bosker, 1999). The proportion of intra- or inter-individual variance accounted for by each set of variables is assessed via the reductions in magnitude of the intercept, slope and level 1 variance components where appropriate. These reductions are viewed analogous to effect sizes (Zickar & Slaughter, 1999).

The *Power in Two-level Designs* program (PINT, Bosker, Snijders, & Guldemon, 2003) was used to estimate whether our sample size was sufficient to detect the relationships of interest. PINT requires the user to estimate specific parameters and then provides estimates of the standard errors for main effects and cross-level interactions, for various sample sizes. Previous research examining similar constructs was used to estimate the parameters (Yeo, 2003; Yeo & Neal, 2004). We calculated the power of our analyses given 12 repeated measurements and approximately 60% of variance in subjective cognitive effort scores residing between individuals. The PINT results indicated that our sample of 99 participants was sufficient to detect small effect sizes at a level of 80% confidence or better with $\alpha = .10$ for the cross-level interactions (assuming standard errors less than or equal to .09) and $\alpha = .05$ for other effects (assuming standard errors less than or equal to .08) (Bosker et al., 2003).

Results and Discussion

Tables 1 and 2 present the descriptive statistics. The mean for the Advanced Progressive Matrices was higher, and the standard deviation was lower, than in other studies using similar populations (Bors & Stokes, 1998; Colom & Garcia-Lopez, 2002). The mean and standard deviation for conscientiousness were higher than other research (Costa & McCrae, 1992; Ramanaiah, Sharpe, & Byravan, 1999). There was a negative correlation between ability and conscientiousness, which is consistent with previous findings in student samples (Moutafi,

Furnham, & Paltiel, 2004). The means for subjective cognitive effort and perceived difficulty were higher, and the standard deviations were lower, than in past research (Yeo & Neal, 2004).

An initial model showed that performance improved over time (penalty scores reduced), $t(1282) = -3.13, p < .01$ at a diminishing rate, $t(1282) = 3.64, p < .01$. This pattern reflects a classic learning curve, and is what would be expected if the participants were becoming more skilled at the task.

Hypotheses were tested by following the 6-Step procedure outlined in the Method section. Step 5 of this process (in which each level 1 predictor was included but level 2 variables were excluded) indicated that the data were autocorrelated, $\chi^2(1) = 8.36, p < .01$, demonstrating that subjective cognitive effort measurements close together were more highly correlated than measurements further away from each other. Repeating Steps 1-4 with this error structure indicated that all results remained the same. These models were used to estimate ICC1 and effect sizes and to report the significance of random effects. Step 1 indicated that the ICC1 for subjective cognitive effort scores was .68, which demonstrates that 68% of the variance in subjective cognitive effort scores was at the inter-individual level. Deviance tests conducted at Step 3 indicated that the random effects associated with the linear, $\chi^2(2) = 48.61, p < .01$ and quadratic, $\chi^2(3) = 29.33, p < .01$ trajectory parameters significantly improved the model fit.

Table 3 shows the results from the final level 1 model. In support of Hypothesis 1, the linear trajectory parameter was significant, indicating that the amount of cognitive effort that participants reported applying to the task declined over trials, $t(98) = -4.13, p < .001$. The quadratic trajectory was not significant, indicating that the rate at which subjective cognitive effort declined had not started to plateau by the end of the experiment, $t(98) = -0.80, p > .05$. The fixed component of the linear trajectory parameter accounted for 7.74% of the intra-individual variance in subjective cognitive effort scores (2.46% total variance), while the random component accounted for an additional 42.91% (13.62% total variance). The unique contribution of the fixed quadratic trajectory parameter accounted for less than 1% of the intra-individual variance (.20% total variance), however its random component accounted for an additional 12.09% (3.84% total variance).

In support of Hypothesis 2a, an increase in perceived difficulty at the intra-individual level was associated with an increase in subjective cognitive effort, $t(1281) = 30.20, p < .001$. Perceived difficulty accounted for an additional 14.89% of the intra-individual variance in subjective cognitive effort scores (4.73% total variance). It also accounted for 40.67% of the inter-individual variance around the intercept (28.94% total variance), and 66.20% and 58.62% of the parameter variance around the linear and quadratic trajectory parameters (.31% and .006% total variance respectively). Consistent with Hypothesis 2b, the intra-individual relationship between perceived difficulty and subjective cognitive effort was moderated by the linear trajectory, $t(1281) = 3.04, p < .05$. The unique contribution of this interaction was less than 1% of the intra-individual variance (.02% total variance), however it accounted for an additional 2.03% and 1.72% of the parameter variance around the linear and quadratic trajectory parameters respectively (.01% and .0002% total variance respectively). As expected, Figure 1 shows that the intra-individual relationship between perceived difficulty and subjective cognitive effort strengthened throughout practice.

Table 4 shows the results from the final level 2 model. Contrary to Hypothesis 3a, the rate at which subjective cognitive effort declined over trials was not moderated by cognitive ability, $t(96) = -.73, p > .01$. In support of Hypothesis 3b, the cross-level interaction between ability and perceived difficulty was significant, $t(1273) = -4.28, p < .001^3$. Figure 2 shows that this intra-individual relationship was strongest for individuals with low cognitive ability.

In support of Hypothesis 4a, conscientiousness was a significant positive predictor of subjective cognitive effort, $t(95) = 2.63, p < .05$. In support of Hypothesis 4b, conscientiousness moderated the linear subjective cognitive effort trajectory, $t(96) = 1.67, p < .10$. Figure 3 indicates that the rate at which subjective cognitive effort declined was slower for individuals with high levels of conscientiousness than for their counterparts. There was also a cross-level interaction between conscientiousness and perceived difficulty, $t(1273) = -3.66, p < .001$ which supported Hypothesis

³Following Hofmann and Gavin (1998), we ran a follow-up analysis to ensure that the interaction between cognitive ability and perceived difficulty was cross-level. This analysis indicated that the cross-level interaction remained significant, and that the corresponding inter-individual interaction was not significant, $t(93) = -1.71, p > .05$.

4c⁴. Figure 4 indicates that the intra-individual relationship between perceived difficulty and subjective cognitive effort was stronger for individuals with low conscientiousness.

The cross-level main effects of cognitive ability and conscientiousness accounted for an additional 3.26% of the inter-individual variance around the subjective cognitive effort intercept (2.32% total variance). Their interactions with the subjective cognitive effort trajectory accounted for an additional 1.25% of the parameter variance around the linear trajectory (.006% total variance). Finally, their cross-level interactions with perceived difficulty accounted for an additional 1.32% of the inter-individual variance around the intercept (.94% total variance) and an additional 5.74% of the parameter variance around the linear trajectory (.03% total variance).

Subjective cognitive effort was significantly negatively related to penalty scores, $b = -72.27$, $t(98) = -7.70$, $p < .001$ ⁵, after controlling for the growth trajectories and perceived difficulty. This finding indicated that higher levels of subjective cognitive effort were related to higher task performance. After controlling for the growth trajectory parameters and perceived difficulty, subjective cognitive effort accounted for 1.11% of the intra-individual variance in task performance (1.03% total variance). It also uniquely accounted for 10.94% of the inter-individual variance around the intercept, 6.82% around the linear trajectory parameter and 13.76% around the quadratic trajectory parameter (.66%, .03% and .002% total variance respectively).

Summary

The findings from Study 1 generally supported our hypotheses. The amount of cognitive effort that individuals reported expending decreased as they became more experienced at the task, and increased when their perceptions of difficulty increased. Moreover, these self-regulatory patterns were moderated by cognitive ability and conscientiousness. Individuals with low conscientiousness reported reducing the amount of cognitive effort that they applied to the task at a faster rate than their counterparts. Individuals with low cognitive ability and high conscientiousness responded

⁴ A follow-up analysis using Hofmann and Gavin's (1998) procedure also indicated that the cross-level interaction involving conscientiousness and perceived difficulty remained significant, while the inter-individual interaction was not significant, $t(93) = -.99$, $p > .05$.

⁵ Based on the results from deviance tests, this model incorporated random effects for the linear and quadratic growth trajectories and a homogenous error structure.

more strongly to changes in perceived difficulty than their counterparts. Finally, the finding that subjective cognitive effort predicted performance supports the validity of our self-report measure.

Study 2

We aimed to address three issues in a follow-up study to strengthen the conclusions drawn from Study 1. The first issue is theoretical and relates to the relatively focused set of measures we assessed in Study 1. Our choice of constructs was guided by theory, but the question remains whether the inclusion of other constructs would change the nature of the relationships found in Study 1. The most likely candidate is goal level. Goals play an important role in self-regulation theory, crossing the boundary between distal and proximal processes (goal-setting and goal-striving phases). Self-regulation theories assume that behavior is goal directed and suggest that the amount of effort that individuals allocate to a task reflects the amount of effort required to achieve their goal (Brehm & Self, 1989; Carver & Scheier, 1998; Kanfer, 1990; Karoly, 1993). It is important to rule out the possibility that the exclusion of goal level may have distorted the conclusions we drew from Study 1. For example, it is possible that the relationships involving perceived difficulty and subjective cognitive effort reported in Study 1 are mediated or moderated by goal level.

The second two issues are methodological and relate to the validity of our perceived difficulty measure and the generalizability of our results. Our most proximal determinant of subjective cognitive effort, perceived difficulty, was assessed by self-report. We validated the self-report measure of cognitive effort against task performance in Study 1, but there was no external validation of the perceived difficulty measure. Finally, the results may be contingent upon the specific experimental conditions used in Study 1. For example, it is not known whether the results would replicate if we used a more difficult task. Thus, Study 2 represented a replication and extension of Study 1. Phase 1 was similar to the Study 1 task, except that the task was more difficult, and we included a measure of self-set goal level. The second phase included an experimental manipulation of task difficulty.

Method

Experimental Task

Phase 1 consisted of 18 trials of 99-second duration, each containing 4 triplets of aircraft. Each triplet included 1 distracter aircraft and 2 target aircraft. The inclusion of distracter aircraft was to increase task demand by diverting participant attention to non-target events. A target event is two aircraft converging on a common waypoint with a distance of passing less than 10km. Phase 2 consisted of 12 trials lasting 66 seconds each. Task difficulty was manipulated within participants by varying the number of distracter aircraft per event (zero, two or four distracters per event). The order in which the trials were presented was randomized for each participant.

Measures

The measures of subjective cognitive effort, perceived difficulty and task performance were the same as those used in Study 1. Self-set goal level was measured with the item “I aim to achieve an error penalty of less than _____ on the next trial.”

Participants and Procedure

Forty-three undergraduate psychology students participated in this study in return for course credit. There were 19 females and 24 males. The procedure was the same as for Study 1, except for the following. To minimize the number of self-report questions participants had to answer, we presented the self-report questions on trials: 1 to 3; 7 to 9; and 13 to 15. Self-set goal level was assessed prior to the trial, while perceived difficulty and subjective cognitive effort were assessed after the trial. In the second phase, the self-report measures were presented on every trial. Feedback was not presented in the second phase. The task took approximately 60 minutes to complete.

Analysis Strategy

Given that the self-report questions were only presented on some trials, we used HLM2 rather than HMLM because it allows missing data at Level 1. Subjective cognitive effort was the dependent variable. In Phase 1, the level 1 predictors were self-set goal level, perceived difficulty, the trajectory parameters and their interactions with self-set goal level and perceived difficulty. In Phase 2, the level 1 predictors were the task difficulty manipulation, self-set goal level, perceived

difficulty and the interaction between self-set goal level and perceived difficulty. In both phases, the level 2 predictor was aggregated self-set goal level.

Results from Study 1 and previous research (Yeo, 2003; Yeo & Neal, 2004) were used to estimate the parameters required by PINT (Bosker et al., 2003). We calculated power given 9-18 (depending on the variables in the model) and 12 repeated measurements for Phases 1 and 2 respectively, and approximately 68% of variance in cognitive effort scores residing between individuals. The PINT results indicated that our sample of 43 participants was sufficient to detect small effect sizes (.20) at a level of 80% confidence or better with $\alpha = .10$ for the cross-level interactions and $\alpha = .05$ for other effects (Bosker et al., 2003).

Results and Discussion

Phase 1

The descriptive statistics are presented in Tables 5 and 6. The means for subjective cognitive effort and perceived difficulty were higher, the standard deviations were lower, and their inter-correlation was weaker than in Study 1. The inter-individual correlation between perceived difficulty and penalty score was non-significant, as opposed to negative in Study 1; while the intra-individual correlation was positive, as opposed to non-significant in Study 1. The correlation between self-set goal level and penalty score was positive at both levels of analysis and goals increased over practice. Challenging goals at the intra-individual level were associated with high effort, but there was no inter-individual level correlation. Goals did not correlate with perceived difficulty at either level.

An initial model indicated that task performance improved over time (penalty scores reduced), $t(642) = -2.20, p < .05$ at a diminishing rate, $t(642) = 2.02, p < .05$. The ICC1 for subjective cognitive effort scores was .64, which indicates that 64% of the variance in subjective cognitive effort scores was at the inter-individual level. Deviance tests suggested that the random effects for the linear trajectory, $\chi^2(2) = 11.87, p < .01$ and perceived difficulty parameters, $\chi^2(3) = 27.91, p < .05$ were

significant, whereas the random effects associated with the quadratic trajectory, $\chi^2(5) = 3.33, p > .05$ and self-set goal level, $\chi^2(3) = 2.35, p > .05$ parameters should be excluded from the model.

Table 7 shows the results from the final level 1 model. The linear trajectory parameter was not significant, $t(42) = -0.24, p > .05$, although the quadratic trajectory was, indicating that subjective cognitive effort increased over the first few trials, before subsequently decreasing, $t(378) = -3.11, p < .01$. The fixed component of the linear trajectory parameter did not account for any of the intra-individual variance in subjective cognitive effort scores, however the random component accounted for 10.14% (3.68% total variance). The unique contribution of the fixed quadratic trajectory parameter accounted for 3.38% of the intra-individual variance (1.22% total variance).

Self-set goal level was not significantly related to subjective cognitive effort, $t(378) = -0.20, p > .05$. As in Study 1, an increase in perceived difficulty at the intra-individual level was associated with an increase in subjective cognitive effort, $t(42) = 3.88, p < .01$. The fixed component of perceived difficulty accounted for an additional 2.7% of the intra-individual variance in subjective cognitive effort scores (.97% total variance). It also accounted for 3.44% of the inter-individual variance around the intercept, and 12.07% of the parameter variance around the linear trajectory (2.19% and .02% total variance respectively). The random component of perceived difficulty accounted for a further 6.76% of the intra-individual variance (2.43% total variance); 5.73% of the inter-individual variance around the intercept and 1.72% of the parameter variance around the linear trajectory (3.65% and .002% total variance respectively). The relationship between self-set goal level and subjective cognitive effort was not moderated by the linear, $t(378) = -0.66, p > .05$ or quadratic, $t(378) = -0.38, p > .05$ trajectory parameters. Unlike Study 1, the intra-individual relationship between perceived difficulty and task performance was not moderated by the linear, $t(378) = 0.57, p > .05$ or quadratic, $t(378) = 0.56, p > .05$ trajectories. Follow-up analyses indicated that self-set goal level did not moderate the effect of perceived difficulty on subjective cognitive effort at the intra-individual level of analysis. Similarly, aggregated self-set goal level did not

moderate the subjective cognitive effort trajectory or the intra-individual relationship between perceived difficulty and subjective cognitive effort.

As expected, subjective cognitive effort was negatively related to penalty scores, $b = -17.89$, $t(42) = -2.78$, $p < .01$, after controlling for the linear and quadratic trajectory parameters, self-set goal level and perceived difficulty. This indicates that higher subjective cognitive effort scores were related to higher task performance. Beyond the control variables, the fixed component of the subjective cognitive effort parameter accounted for 1.96% of the intra-individual variance in task performance scores (1.71% total variance) and 8.2% of the inter-individual variance around the intercept (1.04% total variance). The unique contribution of the random component was less than 1% of the intra-individual variance in task performance (.08% total variance), however it accounted for 35.61% of the inter-individual variance around the intercept (4.52% total variance).

Phase 2

The descriptive statistics are presented in Tables 8 and 9. The mean for difficulty was higher, the mean for effort was lower, their standard deviations were higher and their intercorrelation was stronger than in Phase 1. The inter-individual correlation between perceived difficulty and penalty score was non-significant, while the intra-individual correlation was positive. The correlation between self-set goal level and penalty score was not significant at either level of analysis. Challenging goals were associated with high effort at both levels of analysis. Goals did not correlate with perceived difficulty or the task difficulty manipulation.

The ICC1 for subjective cognitive effort scores was .82, which indicates that 82% of the variance in subjective cognitive effort was at the inter-individual level. Deviance tests suggested that the random effects for the task difficulty manipulation, $\chi^2(2) = 20.28$, $p < .01$ and perceived difficulty parameters, $\chi^2(3) = 53.95$, $p < .01$ were significant, whereas the random effect associated with self-set goal level, $\chi^2(3) = 0.34$, $p > .05$ should be excluded from the model.

Table 10 shows the results from a mediation analysis. Step 1 shows that the task difficulty manipulation was a significant predictor of perceived difficulty, $t(42) = 9.91$, $p < .001$, after

controlling for self-set goal level, indicating that participants perceived the task to be more difficult when more aircraft were present. Step 2 shows that the task difficulty manipulation was a significant predictor of subjective cognitive effort, $t(42) = 3.94, p < .001$, indicating that participants applied more effort to the task when more aircraft were present. The fixed component of the task difficulty manipulation accounted for 6.33% of the intra-individual variance in subjective cognitive effort scores (1.17% total variance). The random component accounted for a further 10.77% of the intra-individual variance (1.98% total variance). Steps 3 and 4 show that perceived difficulty mediated the effect of the task difficulty manipulation. Consistent with Study 1, an increase in perceived difficulty at the intra-individual level was associated with an increase in subjective cognitive effort, $t(42) = 5.26, p < .001$ while controlling for self-set goal level. Moreover, the task difficulty manipulation became non-significant, $t(42) = 0.72, p > .05$. The fixed component of perceived difficulty accounted for an additional 3.2% of the intra-individual variance in subjective cognitive effort scores (.88% total variance). It also accounted for 10.87% of the inter-individual variance around the intercept (8.90% total variance), and 16.80% of the parameter variance around the task difficulty manipulation parameter (.01% total variance). The random component of perceived difficulty accounted for a further 8.18% of the intra-individual variance (1.51% total variance); 19.75% of the inter-individual variance around the intercept and 69.60% of the parameter variance around the task difficulty manipulation parameter (16.17% and .03% total variance respectively). Self-set goal level was not significantly related to subjective cognitive effort, $t(512) = -0.28, p > .05$. Follow-up analyses indicated that self-set goal level did not moderate the effects of the task difficulty manipulation or perceived difficulty on subjective cognitive effort at the intra-individual level of analysis. Similarly, aggregated self-set goal level did not moderate the intra-individual effects of the task difficulty manipulation or perceived difficulty.

The task difficulty manipulation was positively related to penalty scores, $b = 41.00, t(42) = 18.62, p < .001$, after controlling for self-set goal level, perceived difficulty and subjective cognitive effort. This result indicated that participants performed better on the easier trials. The task difficulty

manipulation accounted for 62.03% of the intra-individual variance in task performance (62.01% total variance). Unlike Phase 1, subjective cognitive effort, $b = -3.22$, $t(42) = -0.75$, $p > .05$ was not a significant predictor of task performance.

Summary

There were three major findings from Study 2. First, the inclusion of self-set goal level did not influence the effects of practice or difficulty on effort, suggesting that the exclusion of goal level did not distort the conclusions we drew from Study 1. Second, the measures of perceived difficulty and subjective cognitive effort were sensitive to an experimental manipulation of task difficulty, suggesting that they are valid. Finally, the relationship between perceived difficulty and subjective cognitive effort was replicated in Study 2, despite the changes in the experimental task.

To some, the absence of any effect of goals at the intra-individual level may appear surprising. However, self-regulation theories place goal level towards the middle of the distal-proximal continuum. Whilst goals can change over time in response to repeated success or failure, there is an element of stability to them (Carver & Scheier, 1998; Kanfer, 1990). Goals provide drive, direction and resilience to the motivational system in the face of changes within the environment and the person. If so, the effects of goals may be stronger at the inter-individual level than at the intra-individual level. Our Study 2 results are consistent with this claim. In Phase 1, the correlation between self-set goal level and penalty score was stronger at the inter-individual level ($r = .59$, $p < .001$) than the intra-individual level ($r = .15$, $p < .01$); while the correlation between perceived difficulty and penalty score was stronger at the intra-individual level ($r = .43$, $p < .001$) than the inter-individual level ($r = .21$, ns). A similar pattern emerged in Phase 2 for perceived difficulty, while self-set goal level was not related to penalty score at either level. Previous studies have found similar results. Vancouver et al. (2001) found that self-set goal level only accounted for 3% of the intra-individual level variance in performance. Similar results have been demonstrated for self-efficacy, which is proximally related to goal level (e.g. Heggstad & Kanfer, 2004; Vancouver et

al., 2002). Yeo and Neal (2006) found that self-efficacy accounted for 58% of the variance in performance at the inter-individual level, but less than 1% at the intra-individual level.

There are several differences in findings across the two studies. In Phase 1, subjective cognitive effort initially increased before decreasing, and perceived difficulty did not interact with practice. In Phase 2, the relationship between subjective cognitive effort and performance did not replicate. These differences may reflect the higher difficulty level in Study 2. We suspect that participants needed to increase subjective cognitive effort over the first few trials of Phase 1, because the task was more difficult than they expected. The task difficulty may have also slowed any changes that occur with practice among perceived difficulty and subjective cognitive effort. The task was even more difficult in Phase 2. Resource allocation theory predicts that there comes a point when increases in effort can no longer compensate for increases in difficulty, and the relationship between effort and performance breaks down (Norman & Bobrow, 1975). Participants may have reached that point in Phase 2 of Study 2.

There were also differences across the studies in the correlations between perceived difficulty and performance at the two levels of analysis. At the intra-individual level, the correlation between perceived difficulty and penalty score was non-significant in Study 1, and positive in Study 2. The positive correlation indicates that participants performed worse on trials that they perceived to be more difficult. At the inter-individual level, the correlation between perceived difficulty and penalty score was negative in Study 1 and non-significant in Study 2. The negative correlation indicates that individuals who, on average, reported the task to be more difficult than their counterparts performed better. Given the differences in the correlations, we ran follow-up analyses for both studies using performance as the dependent variable. Results consistently showed that perceived difficulty was detrimentally related to performance at the intra-individual level, but beneficially related at the inter-individual level. At present, we do not have a convincing explanation for the beneficial effect of perceived difficulty at the inter-individual level. This effect does not appear to be due to effort or goal level. The effect of average subjective effort on performance was not significant at the inter-

individual level after controlling for its effect at the intra-individual level, and goal level was unrelated to perceived difficulty. An alternative explanation could be that people who perceived the task to be difficult discovered more effective strategies than their counterparts. However, this account is speculative, as we do not have data regarding task or meta-cognitive strategies.

General Discussion

Our goal was to examine the factors that influence changes in subjective cognitive effort. Study 1 demonstrated two key findings. The first relates to the way that subjective cognitive effort changes as individuals become more skilled at a task. An individual's level of conscientiousness influenced the rate at which subjective cognitive effort declined throughout skill acquisition. The second finding relates to the way that individuals react to perceptions of task difficulty. The intra-individual relationship between perceived difficulty and subjective cognitive effort strengthened throughout skill acquisition. Moreover, we have shown that cognitive ability and conscientiousness can influence the degree to which individuals react to perceptions of task difficulty. Study 2 provided converging evidence regarding the validity of our measures. We believe that these findings make a modest, but useful, contribution to the motivation literature.

Changes in Cognitive Effort Over Time

Conscientiousness moderated the cognitive effort trajectory. Individuals with low conscientiousness reported reducing their cognitive effort at a faster rate than their counterparts. There are two potential explanations for this finding. The first explanation relates to the motivational properties of conscientiousness. Perseverance is one of the primary behavioral indicators of conscientiousness (Barrick et al., 1993). Given that individuals with high levels of conscientiousness are expected to be self-disciplined and committed to their goals (Barrick & Mount, 1991), they should persist with high levels of cognitive effort, despite the fact that the amount of cognitive effort required to perform the task is decreasing.

An alternative explanation relates to the rate of skill acquisition. In time pressured tasks, the performance of highly conscientious individuals has been shown to improve more slowly than for

their counterparts (Yeo & Neal, 2004). However, if the effect of conscientiousness on the subjective cognitive effort trajectory reflects differences in skill acquisition rates, then we would expect the same interaction to emerge when cognitive ability is used as the moderator. However, ability did not influence the rate at which subjective cognitive effort decreased over time. We carried out a follow-up analysis examining whether conscientiousness or cognitive ability predicted *performance* growth trajectories. Given that task performance showed the characteristics of a classic learning curve, it is reasonable to assume that the performance improvement reflected skill acquisition. However, neither conscientiousness nor ability predicted individual differences in these performance trajectories. Therefore, it is unlikely that the effect of conscientiousness on the *cognitive effort* trajectory reflects differences in the rate of skill acquisition. Rather, it appears that the interaction reflects the motivational properties of conscientiousness.

Reactions to Perceptions of Task Difficulty

Different people reacted differently to perceptions of difficulty. Individuals with low cognitive ability or low conscientiousness reacted more strongly to perceptions of task difficulty than their counterparts. In the case of ability, we believe that this interaction reflects differences in resource capacity. Low ability individuals need to react more strongly to changes in difficulty, relative to their counterparts, because they have fewer resources available. These results suggest that cognitive ability can influence the way that individuals respond to feedback during task engagement. We believe the interaction between conscientiousness and perceived difficulty reflects the tendency of highly conscientious individuals to work consistently hard – they appear to persist with high levels of cognitive effort regardless of task difficulty. By comparison, those with low conscientiousness appear to reserve high levels of cognitive effort for when the task is perceived to be particularly difficult. These results suggest that stable behavioral tendencies associated with conscientiousness can influence the way that individuals respond to feedback during task engagement.

Measurement Issues

Potential limitations of this research are that our measures of cognitive effort and difficulty were measured with single item self-report questions and they were always assessed together. First, it is true that self-report measures can be problematic (Pedhazur & Schmelkin, 1991). However, evidence suggests that gaining immediate measurements of psychological states enhances the accuracy of self-reports (Diener, 1995; Ericsson & Simon, 1980; Hedges, 1985). Furthermore, our measure of subjective cognitive effort was validated against a measure of task performance in both studies, and our measure of perceived difficulty was validated against a manipulation in Study 2.

Second, it is possible that assessing subjective cognitive effort and perceived difficulty together might make it hard for participants to respond to the items differentially. However, the fact that the relationship between these two variables changed throughout practice suggests that participants could differentiate between the constructs. Also, these constructs were differentially related to conscientiousness, performance, self-set goal level, and had different growth trajectories.

Finally, recent research suggests that the psychometric properties of single-item measures can equal that of multi-item measures for a variety of psychological constructs, such as job satisfaction (Nagy, 2002), college teaching effectiveness (Wanous & Hudy, 2001), and attitudes towards marketing (Bergkvist & Rossiter, 2007). Theorists explain these findings by arguing that single items are sufficient for relatively narrow or unambiguous constructs (Rossiter, 2002; Sackett & Larson, 1990). Our constructs of cognitive effort and difficulty meet this criterion because they are uni-dimensional (for a similar argument, see Maslyn & Uhl-Bien, 2001) and our real-time measurement technique reduces the possibility of ambiguity (Ericsson & Simon, 1980). A review of the literature supports this claim because multi-item self-report measures of cognitive effort do not appear to yield higher validity in relation to performance (Bray & Whaley, 2001; Brown & Leigh, 1996; Byrne, Stoner, Thompson, & Hochwarter, 2005; Chang, 2003; Christen, Iyer, & Soberman, 2006; Wolters, 2000) than single item measures (Schmitz & Skinner, 1993; Terborg & Miller, 1978; Yeo & Neal, 2004). Also, single-item measures of effort have been validated against

psychophysical indices of mental effort (e.g. spectral variations in heart period variability, Veltman & Gaillard, 1993; Zijlstra, 1993).

Boundary Conditions and Extensions

In the current research, we have established a theoretical and methodological framework for examining the roles that states and traits play in the subjective experience of cognitive effort allocations. There are a number of ways in which this framework can be extended. First, future work could examine the boundary conditions that act on the relations among proximal motivational processes. The task itself plays an important role in constraining the relations among practice, difficulty, effort, and performance. For example, tasks that involve inconsistent information processing demands are learnt more slowly than those involving consistent information processing demands, and cannot be automated. Thus, the amount of effort required by inconsistent information processing tasks should remain high for longer, and we may observe flatter effort trajectories compared to those found for consistent information processing tasks. Similarly, a positive effort trajectory may emerge in tasks that steadily increase in difficulty level. Also, the way that individual differences influence the effort trajectory may differ depending on the nature and stability of the task. For example, if the task involves inconsistent information processing, then individual differences in effort trajectories may be more strongly predicted by ability than conscientiousness (Sackett, Zedeck, & Fogli, 1988; Weiss & Adler, 1984).

Distal motivational processes may also constrain the relations among proximal processes. For example, self-regulation theory predicts that people will respond to increases in difficulty with increases in effort, until they reach the point of maximum potential motivation, at which point they will withdraw effort (Brehm & Self, 1989; Carver & Scheier, 1998). Variables that are expected to influence an individual's maximum potential motivation include ability, conscientiousness, valence, instrumentality, self-efficacy and goal commitment. For example, under conditions of increasing difficulty, individuals with low cognitive ability or low conscientiousness might withdraw effort at an earlier stage than their counterparts.

Second, future work could examine the interplay among distal and proximal processes. The challenge associated with this endeavour is to match the sampling intervals to the different time scales at which distal and proximal processes operate, and to analyze the relationships among variables across these different time scales. For example, we argued earlier that goals and self-efficacy fall towards the middle of the distal-proximal continuum. Within the distal motivational process, factors such as efficacy beliefs influence choices regarding goal level, which set the stage for the proximal regulation of behaviour whilst striving for that goal (Carver & Scheier, 1998; Kanfer & Heggstad, 1999). Consistent with the notion of goal hierarchies, however, distal processes are also responsible for setting sub-goals whilst the individual is striving for a higher-level goal (Vancouver, 2005). Moreover, goals at almost any level of the hierarchy can be expected to change over time, albeit at different rates (Carver & Scheier, 1998). Therefore, it is possible that the strength of goal and self-efficacy effects on effort and performance depend on their level in the hierarchy. For example, existing within-person research has focussed on relatively low levels of the hierarchy (e.g. performance trial) and shown weak effects at the intra-individual level (Vancouver et al., 2002; Vancouver et al., 2001; Yeo & Neal, 2006). It is possible that goals and self-efficacy do exert substantive effects at the intra-individual level, but from a higher point in the goal hierarchy.

Third, future work could examine the determinants of choices regarding the direction of effort. We constrained choices regarding the direction of effort by having participants work on a single task. Future studies could examine the direction of effort by using tasks that have competing goals. These studies would need to include the distal processes that are responsible for choosing the total proportion of resources that will be devoted to a task and setting the desired level of performance.

Conclusion

This research contributes to understanding of the factors that influence changes in subjective cognitive effort during skill acquisition. We integrated trait approaches with dynamic state approaches to examine potential determinants of subjective cognitive effort from two levels of analysis. Our results suggest that subjective cognitive effort is influenced by the stage of skill

acquisition and both perceived and manipulated task difficulty and that an individual's cognitive ability and conscientiousness influences his or her self-regulatory patterns. There is scope for continuing research within this paradigm, and extending this research by examining a broader range of constructs. Overall, this research makes a useful contribution to the growing body of work that is using within-person designs and analysis techniques to examine dynamic motivational processes.

Table 1

*Study 1: Descriptive Statistics and Intercorrelations among the Variables at the Inter-individual**Level (N = 99)*

Variable	<i>M</i>	<i>SD</i>	1	2	3	4
1. Average task performance scores ^{ab}	234.33	85.82	—			
2. Average perceived difficulty ^a	5.29	1.79	-.24*	—		
3. Advanced progressive matrices	25.27	5.04	-.40***	-.07	—	
4. Conscientiousness	160.21	25.32	.12	.12	-.25*	—
5. Average subjective cognitive effort ^a	6.20	2.07	-.28**	.64***	.05	.23*

* $p < .05$. ** $p < .01$. *** $p < .001$.

^a “Average” measures represent the individual’s average score across the 13 trials.

^b Task performance is represented by penalty scores, so lower scores reflect higher performance.

Table 2

Study 1: Descriptive Statistics and Intercorrelations among the Variables at the Intra-Individual Level (N = 1287)

Variable	<i>M</i>	<i>SD</i>	1	2	3
1. Task performance ^a	234.33	261.95	—		
2. Linear trajectory	—	—	-.10***	—	
3. Perceived difficulty	5.29	2.14	.04	-.04	—
4. Subjective cognitive effort	6.20	2.31	-.06*	-.09**	.66***

* $p < .05$. ** $p < .01$. *** $p < .001$.

^a Task performance is represented by penalty scores, so lower scores reflect higher performance.

Table 3

Study 1: Final Level 1 Model

Fixed effects	Coefficient	SE
Intercept, π_{00}	6.20***	0.16
Linear trajectory, π_{10}	-0.04***	0.01
Quadratic trajectory, π_{20}	-0.002	0.002
Perceived difficulty, π_{30}	0.55***	0.04
Linear trajectory X Perceived difficulty, π_{40}	0.01**	0.004

Note. An earlier model indicated that the interaction among the quadratic trajectory and perceived difficulty was not significant. Given that it is not involved in any cross-level interaction hypotheses, it was removed from the model. Exclusion of it did not change the substantive interpretation of results.

* $p < .05$. ** $p < .01$. *** $p < .001$.

Table 4

Study 1: Final Level 2 Model

Fixed effect	Coefficient	SE
Intercept, π_{00}		
Intercept, λ_{00}	6.21***	0.15
Advanced progressive matrices, λ_{01}	0.05	0.03
Conscientiousness, λ_{02}	0.91**	0.34
Linear trajectory, π_{10}		
Intercept, λ_{10}	-0.04***	0.01
Advanced progressive matrices, λ_{11}	-0.001	0.002
Conscientiousness, λ_{12}	0.04†	0.02
Quadratic trajectory, π_{20}		
Intercept, λ_{20}	-0.002	0.002
Advanced progressive matrices, λ_{21}	-0.0001	0.0004
Conscientiousness, λ_{22}	-0.004	0.005
Perceived difficulty, π_{30}		
Intercept, λ_{30}	0.55***	0.02
Advanced progressive matrices, λ_{31}	-0.02***	0.004
Conscientiousness, λ_{32}	-0.15***	0.04
Linear trajectory X Perceived difficulty, π_{40}		
Intercept, λ_{40}	0.01*	0.004

† $p < .10$. * $p < .05$. ** $p < .01$. *** $p < .001$.

Table 5

Study 2 Phase 1: Descriptive Statistics and Intercorrelations among the Variables at the Individual Level (N = 43)

Variable	<i>M</i>	<i>SD</i>	1	2	3	4
1. Average task performance scores ^{ab}	214.99	74.23	—			
2. Average self-set goal level ^{ab}	145.95	114.13	.59***	—		
3. Average perceived difficulty ^a	5.44	1.46	.21	.05	—	
4. Average subjective cognitive effort ^a	7.27	1.66	-.32*	-.23	.23	—

* $p < .05$. ** $p < .01$. *** $p < .001$.

^a “Average” measures represent the individual’s average score across the 18 trials.

^b Task performance is represented by penalty scores, so lower scores reflect higher performance.

Similarly, higher self-set goal scores reflect easier goals.

Table 6

Study 2 Phase 1: Descriptive Statistics and Intercorrelations among the Variables at the Intra-Individual Level (N = 774, or 387^a)

Variable	<i>M</i>	<i>SD</i>	1	2	3	4	5
1. Task performance ^b	214.99	240.87	—				
2. Linear trajectory	—	—	-.09*	—			
3. Self-set goal level ^b	145.95	175.48	.15**	-.29***	—		
4. Perceived difficulty	5.44	2.39	.43***	.10	-.04	—	
5. Subjective cognitive effort	7.27	2.01	-.09	.01	-.14**	.21***	—

* $p < .05$. ** $p < .01$. *** $p < .001$.

^a Task performance was measured on each of 18 trials; whereas self-set goal level, perceived difficulty and subjective cognitive effort were measured on nine trials.

^b Task performance is represented by penalty scores, so lower scores reflect higher performance. Similarly, higher self-set goal scores reflect easier goals.

Table 7

Study 2 Phase 1: Final Level 1 Model

Fixed effects	Coefficient	SE
Intercept, π_{00}	7.35***	0.24
Linear trajectory, π_{10}	-0.004	0.12
Quadratic trajectory, π_{20}	-0.003**	0.001
Self-set goal level, π_{30}	-0.0001	0.0005
Perceived difficulty, π_{40}	0.14*	0.04
Linear trajectory X Self-set goal level, π_{50}	-0.0001	0.0001
Quadratic trajectory X Self-set goal level, π_{60}	-0.000002	0.000006
Linear trajectory X Perceived difficulty, π_{70}	0.004	0.01
Quadratic trajectory X Perceived difficulty, π_{80}	0.0003	0.001

* $p < .05$. ** $p < .01$. *** $p < .001$.

Table 8

Study 2 Phase 2: Descriptive Statistics and Intercorrelations among the Variables at the Individual Level (N = 43)

Variable	<i>M</i>	<i>SD</i>	1	2	3	4
1. Average task performance ^{ab}	432.75	65.65	—			
2. Average self-set goal level	103.86	116.87	-.19	—		
3. Average perceived difficulty	5.72	1.88	-.10	-.13	—	
4. Average subjective cognitive effort	7.09	2.19	-.10	-.35*	.38*	—

* $p < .05$. ** $p < .01$. *** $p < .001$.

^a “Average” measures represent the individual’s average score across the 12 trials.

^b Task performance is represented by penalty scores, so lower scores reflect higher performance.

Table 9

Study 2 Phase 2: Descriptive Statistics and Intercorrelations among the Variables at the Intra-Individual Level (N = 516)

Variable	<i>M</i>	<i>SD</i>	1	2	3	4	5
1. Task performance ^a	432.75	356.95	—				
2. Task difficulty manipulation	—	—	.76***	—			
3. Self-set goal level	103.86	139.11	-.03	-.02	—		
4. Perceived difficulty	5.72	2.48	.30***	.37***	-.08†	—	
5. Subjective cognitive effort	7.09	2.38	.09*	.11*	-.26***	.36***	—

† $p < .10$. * $p < .05$. ** $p < .01$. *** $p < .001$.

^a Task performance is represented by penalty scores, so lower scores reflect higher performance.

Table 10

Study 2 Phase 2: Mediation Analysis

Fixed effects	Coefficient	SE
Step 1: DV = perceived difficulty		
Intercept, π_{00}	5.72***	.29
Task difficulty manipulation, π_{10}	.14***	.01
Self-set goal level, π_{20}	.001	.001
Step 2: DV = subjective cognitive effort		
Intercept, π_{00}	7.09***	.33
Task difficulty manipulation, π_{10}	.04***	.01
Steps 3 & 4: DV = subjective cognitive effort		
Intercept, π_{00}	7.08***	.28
Task difficulty manipulation, π_{10}	.01	.01
Self-set goal level, π_{20}	-.0001	.0004
Perceived difficulty, π_{30}	.26***	.05

* $p < .05$. ** $p < .01$. *** $p < .001$.

Figure Captions

Figure 1. The intra-individual interaction between perceived difficulty and practice.

Figure 2. The cross-level interaction between cognitive ability and perceived difficulty.

Figure 3. The cross-level interaction between conscientiousness and practice.

Figure 4. The cross-level interaction between conscientiousness and perceived difficulty.

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