Complex task performance is predicted by integrative skill domain ability

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SUMMARY

This paper presents a reanalysis of Lee et al's (2012) skill acquisition data to test whether performance in a complex integrated task, based on fighter pilot attributes, is predicted by integrative skill domain ability. The findings show that the integrative skill domain ability is predictive of performance in a complex integrated task. In addition, more common individual difference measures like cognitive ability, working memory, attention control, and work sample testing, are either not predictive of performance or less predictive than the integrative skill domain ability.

KEYWORDS

Skill domain, performance, individual differences

Introduction

Psychological skill domains are a way to classify categories of cognitive processes underlying skills. Complex cognitive skill domains classify effortful cognitive processes that place significant demands on cognitive resources for the effective completion of tasks. One of these domains is the Integrative skill domain, which "*represents the ability of an individual to manage their attention to integrate and coordinate two or more concurrent psychological domains*" (Cahillane et al., 2022, p.10). This domain is required for complex integrated tasks where two or more components, underpinned by different psychological skill domains, must be performed concurrently rather than separately. High-risk tasks, representative of the application of the Integrative skill domain, are numerous, with piloting a fighter jet being a prominent example of a complex integrated task.

The potential effect of skill domain abilities on performance differs from the concept of skill transfer as, unlike task-specific skills, the psychological skill domains are not context specific. Instead, these domains can be considered "modes" of cognition, underpinned by different psychological processes and associated neural pathways (Lam et al., 2022; Strick et al., 2021, Worringer et al., 2019). As actionable modes of cognition they can be considered a form of individual difference. As such, measuring ability in relation to psychological skill domains could support the identification of operators with the required level of ability for effective performance during a given task.

In the context of the Integrative skill domain, as different complex integrated tasks share the same mode of cognition and neural areas (Ding et al., 2024, Peters et al., 2019), their performance is likely to be correlated as they rely on the same skill domain ability. This is especially true for Space Fortress performance; its relative difficulty and the integration of a wide-ranging variety of sub-tasks (Donchin, 1989) mean that performance in this task will likely impose a high cognitive load related to all the psychological and cognitive processes shared between complex integrated tasks. However, simpler, though still complex, integrated tasks, by not being as comprehensive, are more

likely to only partially and unevenly load shared psychological processes and neural pathways (Leone et al., 2017). As they are likely to represent different load distributions, integrating multiple measures of simpler integrated tasks together should help with creating a measure that is more representative of individual performance across the whole shared neuro-cognitive pathway for complex integrated tasks. Such a composite measure should be predictive of very complex integrated task performance, as with Space Fortress, by representing integrative skill domain ability.

Various individual differences have already been used to predict performance in complex tasks, including multitasking paradigms (Ackerman, 1992; Draheim et al., 2022; Redick et al., 2016), but no research has been done considering complex integrated tasks as a category. Among individual differences, cognitive ability is one of the most studied constructs, with a robust effect on performance, though the effect seems to be smaller in recent literature (Berry, 2024). Cognitive ability, along with measures of memory and attention control, have found practical applications in personnel selection (Broach et al., 2019). However, cognitive ability measurements have been criticised as having an unequal effect for certain demographics, leading to an adverse impact within personnel selection (Burgoyne et al., 2021). Attention control and work sample tests have been proposed as alternative measurements (Burgoyne et al., 2021; Campion et al. 2019) although they have a limited association with performance (Roth et al., 2005).

Methods

Space Fortress is a video game representative of a complex integrated task. It is based on fighter pilot attributes, with motor demands, a need for visual monitoring and scanning, memory requirements (Donchin, 1989) and concurrent performance of skills underpinned by different psychological domains. This paper presents a reanalysis of Lee et al.'s (2012) data to examine whether a measure of Integrative skill domain ability predicts complex integrated task performance in Space Fortress, and how this compares with the predictive ability of existing individual difference measures.

In Lee et al.'s (2012) original experiment, 75 participants completed up to 15 sessions practicing Space Fortress in one of three conditions. The conditions were either a control, with three practice sessions, full emphasis training, with 15 sessions, or hybrid variable-priority training, with 15 sessions where the instructions changed. Each participant also completed three batteries of tests at the beginning, middle and end of the session series. Each test battery measured individual differences in cognitive ability, working memory, attention control, plus motor ability (single joystick task), a component skill of Space Fortress (piloting task, can be considered a work sample test), and performance in integrated complex tasks (radar monitoring task and dual-joystick task). For the reanalysis, we combined the two integrated complex task performance scores to obtain a composite measure representative of integrative skill domain ability. The regression analyses performed controlled for condition by session interactions. All the continuous variables (results of the test batteries and performance scores in Space Fortress) were Z-normalised. Data from each of the three batteries of test was regressed on the performance scores from the practice session which immediately followed. As the data had repeated measures and the residuals approximated a normal distribution, every regression was a robust linear mixed model (k=1.345, s=10). Every β reported is a standardised coefficient.

Results

Single skill domain multitasking, as represented by performance in an attention blink paradigm, mapped to a perceptual-visual domain, was not significantly predictive of performance[1] ($p = 0.749$, $t = 0.320$). Similarly, none of the individual difference measures of cognitive ability (Raven's

[1] Unless specified otherwise, the following regressions are controlled for the component skill.

progressive matrices: p=0.842, t=0.199), working memory (Sternberg memory task: p=0.079, t=1.764) or attention control (Flanker task: p=0.299, t=1.041) had a significant effect on performance. The component skill measure significantly predicts performance[2] (Piloting task: p=0.003, t=3.051; β =0.158, se=0.052), however the composite measure of Integrative skill domain ability has a stronger relationship with performance (integrative domain ability: p<0.001, t=5.311; β =0.221, se=0.042). This is reversed for the control sub score[3], the score where the component skill is most relevant, with the component skill explaining more variance than integrative skill domain ability (component skill: p<0.001, t=5.515; β =0.282, se= 0.051; integrative domain ability: p<0.001, t=3.494; β =0.154, se=0.044).

The individual measures that compose the integrative skill domain ability are less predictive of performance than the composite (radar monitoring: p=0.002, t=3.228; β =0.131, se= 0.041; dual joystick: p <0.001, t=3.930; β =0.167, se=0.043), validating the use of a combined measure, and they are uncorrelated (r(196)=0.020, p=0.783). A physical task representative of the Continuous psychomotor skill domain and fluency in the controls used by Space Fortress (i.e., use of a joystick), was not predictive of overall Space Fortress performance[4] (single joystick task: p=0.156, t=1.426).

Discussion

A significant effect of integrative skill domain ability on performance of the complex integrated task, Space Fortress, was found across training length and conditions. By contrast, individual differences in cognitive ability, working memory and attention control, which have previously been found to be significantly associated with overall complex integrated task performance (Redick et al., 2016) do not reach significance here, showing that they have more limited generalisability in explaining complex integrated task performance. Even a skill integral to Space Fortress performance and a form of work sample test, the component skill, and a skill that reflects the form of psychomotor control used in Space Fortress, have less influence than integrative skill domain ability on overall Space Fortress performance. This is a marked difference from the literature on skill transfer, where skill proximity to the task dictates the strength of the relationship between the two (Sala et al., 2019). A caveat to these results is that initial integrative skill domain ability does not predict long term performance, unlike the component skill.

Consequently, operator proficiency in, or potential capability for, complex integrated task performance could, in part, be trained and assessed more effectively by combining multiple simpler tasks that still require the integrative skill domain. This is because, in a standardised environment, one might assume that integrative skill domain ability is the primary limiting factor of performance, given the results from this study. If this holds true across applied settings, the design of complex integrated systems would benefit from regarding concurrent multi-task completion as the main challenge to satisfactory performance, rather than memory or attention. Designers of such systems should thereafter plan accordingly, limiting the operator multi-tasking requirements as much as possible and/or selecting people who are known to perform well in this domain. As the relationship between integrative skill domain ability and complex integrated task performance is maintained across training conditions, this ability and its underlying neuro-cognitive pathway are likely

[2] This regression is controlled for the composite score instead of the component skill.
[3] Subset of the Space Fortress score which tracks whether the player remains within the bounds of a hexagon visible on screen.
[4] This regression controls for the composite score instead of the component skill because of a lower Bayesian Information Criterion for this model.

affected by practice, suggesting targeted training interventions as an alternative to highly selective personnel recruitment.

Future research should confirm the assumption that this ability is the primary limiting factor of operator performance in applied environments. It should also aim to measure the benefits of an intervention, on individual integrative skill domain ability, for supporting complex integrated task acquisition compared to more traditional approaches. It would also be useful to examine whether the predictive power of integrative skill domain ability on performance generalises to other psychological skill domains. The findings have implications for personnel selection, transferability of experience and training.

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Data supporting this study cannot currently be made available due to multiple third-party restrictions. Contact the lead author if you require access at adrien.jouis@cranfield.ac.uk

References

Ackerman, P. L. (1992). Predicting individual differences in complex skill acquisition: Dynamics of ability determinants. *Journal of Applied Psychology*, *77*(5), 598–614. https://doi.org/10.1037/0021-9010.77.5.598

Berry, C. M. (2024). Personnel selection systems and diversity. *Current Opinion in Psychology*, *60*, 101905. https://doi.org/10.1016/j.copsyc.2024.101905

Broach, D., Schroeder, D. & Gildea, K. (2019) *Best Practices in Pilot Selection*. Office of Aerospace Medicine (DOT/FAA/AM-19/06). https://rosap.ntl.bts.gov/view/dot/57077

Burgoyne, A. P., Mashburn, C. A., & Engle, R. W. (2021). Reducing adverse impact in high-stakes testing. *Intelligence*, *87*, 101561. https://doi.org/10.1016/j.intell.2021.101561

Cahillane, M., MacLean, P. & Anderson, T. (2022). *Competence Retention Analysis Handbook*. Human and Social Sciences Research Capability (HSSRC) Technical Deliverable to UK MOD. O-HSSRC-1.004-029.

Campion, M. C., Campion, E. D., & Campion, M. A. (2019). Using practice employment tests to improve recruitment and personnel selection outcomes for organizations and job seekers. *Journal of Applied Psychology*, *104*(9), 1089–1102. https://doi.org/10.1037/apl0000401

Ding, Q., Ou, Z., Yao, S., Wu, C., Chen, J., Shen, J., Lan, Y., & Xu, G. (2024). Cortical activation and brain network efficiency during dual tasks: an fNIRS study. *NeuroImage*, 120545. https://doi.org/10.1016/j.neuroimage.2024.120545

Donchin, E. (1989). The learning strategies project. *Acta Psychologica*, *71*(1-3), 1–15. https://doi.org/10.1016/0001-6918(89)90002-4

Draheim, C., Pak, R., Draheim, A. A., & Engle, R. W. (2022). The role of attention control in complex real-world tasks. *Psychonomic Bulletin & Review*, *29*(4). https://doi.org/10.3758/s13423-021-02052-2

Lam, T. K., Vartanian, O., & Hollands, J. G. (2022). The brain under cognitive workload: Neural networks underlying multitasking performance in the multi-attribute task battery. *Neuropsychologia*, *174*, 108350. https://doi.org/10.1016/j.neuropsychologia.2022.108350

Lee, H., Boot, W. R., Basak, C., Voss, M. W., Prakash, R. S., Neider, M., Erickson, K. I., Simons, D. J., Fabiani, M., Gratton, G., Low, K. A., & Kramer, A. F. (2012). Performance gains from

directed training do not transfer to untrained tasks. *Acta Psychologica*, *139*(1), 146–158. https://doi.org/10.1016/j.actpsy.2011.11.003

Leone, C., Feys, P., Moumdjian, L., D'Amico, E., Zappia, M., & Patti, F. (2017). Cognitive-motor dual-task interference: A systematic review of neural correlates. *Neuroscience & Biobehavioral Reviews*, *75*, 348–360. https://doi.org/10.1016/j.neubiorev.2017.01.010

Peters, S., Eng, J. J., Liu-Ambrose, T., Borich, M. R., Dao, E., Amanian, A., & Boyd, L. A. (2019). Brain activity associated with Dual-task performance of Ankle motor control during cognitive challenge. *Brain and Behavior*, *9*(8). https://doi.org/10.1002/brb3.1349

Redick, T. S., Shipstead, Z., Meier, M. E., Montroy, J. J., Hicks, K. L., Unsworth, N., Kane, M. J., Hambrick, D. Z., & Engle, R. W. (2016). Cognitive predictors of a common multitasking ability: Contributions from working memory, attention control, and fluid intelligence. *Journal of Experimental Psychology: General*, *145*(11), 1473–1492. https://doi.org/10.1037/xge0000219

Roth, P. L., Bobko, P., & Mcfarland, L. A. (2005). A Meta-Analysis Of Work Sample Test Validity: Updating And Integrating Some Classic Literature. *Personnel Psychology*, *58*(4), 1009–1037. https://doi.org/10.1111/j.1744-6570.2005.00714.x

Sala, G., Aksayli, N. D., Tatlidil, K. S., Tatsumi, T., Gondo, Y., & Gobet, F. (2019). Near and Far Transfer in Cognitive Training: A Second-Order Meta-Analysis. *Collabra: Psychology*, *5*(1), 18. https://doi.org/10.1525/collabra.203

Strick, P. L., Dum, R. P., & Rathelot, J.-A. (2021). The Cortical Motor Areas and the Emergence of Motor Skills: A Neuroanatomical Perspective. *Annual Review of Neuroscience*, *44*(1). https://doi.org/10.1146/annurev-neuro-070918-050216

Worringer, B., Langner, R., Koch, I., Eickhoff, S. B., Eickhoff, C. R., & Binkofski, F. C. (2019). Common and distinct neural correlates of dual-tasking and task-switching: a meta-analytic review and a neuro-cognitive processing model of human multitasking. *Brain Structure and Function*, *224*(5), 1845–1869. https://doi.org/10.1007/s00429-019-01870-4