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Metacognitive strategies in translation: a comparative study of student and professional translators

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Translation expertise significantly influences how translators manage cognitive resources, yet the specific ways in which professional and novice translators differ in their metacognitive strategy use remain incompletely understood. This gap is particularly evident in specialised contexts such as academic translation, where complex terminology and intricate syntactic structures pose unique cognitive challenges. This study investigated how professional and student translators deploy metacognitive strategies when translating academic texts from Chinese to English, focusing on differences in cognitive resource allocation across translation stages. The study compared 30 professional translators and 30 graduate students in translation studies as they translated two academic article introductions. Using keystroke logging, we recorded detailed temporal data about participants' translation processes, including thinking time, writing time, and resource consultation patterns. Quantitative analysis revealed that professional translators demonstrated significantly shorter thinking times compared to students, while maintaining higher writing-to-thinking ratios. Analysis of cognitive resource distribution showed that professionals maintained more consistent engagement across translation stages compared to students' more variable patterns. These findings suggest that translation expertise manifests not merely in faster processing times, but in qualitatively different approaches to cognitive resource allocation. Professional translators demonstrated greater flexibility in switching between automatic and controlled processes, adapting their strategies according to textual challenges. These results refine our understanding of translation expertise while offering practical implications for translator training, suggesting specific ways to help novice translators develop more efficient cognitive strategies. The study contributes to translation process research by providing empirical evidence of how expertise shapes metacognitive strategy use in specialised translation contexts.

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Introduction

Translation studies has increasingly recognised the critical role of cognitive processes in understanding how translators navigate between languages, cultures, and meaning-making. This cognitive turn in translation research has led to growing interest in metacognitive strategies—the higher-order thinking processes that enable translators to plan, monitor, and evaluate their translation decisions. While seminal works by Gerloff (1986), Jääskeläinen (1993), and Krings (1986) established foundational insights into translators' cognitive mechanisms, significant questions remain about how expertise shapes these processes, particularly in specialised translation contexts.

The relationship between translation expertise and metacognitive strategy use represents a crucial yet underexplored area of enquiry. While studies have demonstrated that professional translators generally exhibit more efficient cognitive processes (Deckert, 2019; Shreve, 2006a), the specific ways in which expertise influences metacognitive strategy deployment remain unclear. This knowledge gap is particularly evident in the context of academic translation, where complex terminology and intricate syntactic structures pose unique cognitive challenges (Ayomi et al., 2020; Peterlin, 2014).

Recent advances in translation process research have enhanced our ability to investigate these cognitive dimensions empirically. While traditional methodologies relied heavily on retrospective reporting, contemporary approaches enable more objective examination of translation processes. However, the application of these methodological advances to understanding metacognitive strategy use, particularly in comparing novice and expert translators, remains limited. This limitation is especially notable in the context of academic translation, where the cognitive demands of specialised discourse require sophisticated metacognitive control.

The present study addresses these gaps by investigating how professional and student translators deploy metacognitive strategies when translating academic texts from Chinese to English. Specifically, this research examines:

1. How do metacognitive strategy patterns differ between professional and student translators in academic translation tasks?
2. In what ways do these strategies evolve across different stages of the translation process?
3. What insights can detailed analysis of cognitive resource allocation reveal about the development of translation expertise?

By focusing on academic translation, this study contributes to our understanding of how expertise shapes metacognitive processes in handling specialised texts. The findings have important implications for translation theory, particularly in refining our understanding of how automatic and controlled processes interact in expert performance. Moreover, the results offer practical insights for translator training, suggesting specific ways to help novice translators develop more efficient cognitive strategies.

This investigation is particularly timely given the growing demand for academic translation and the need for evidence-based approaches to translator training. By examining how expertise influences metacognitive strategy use in academic translation, this study addresses a significant gap in current research while offering practical insights for improving translator education and professional development.

Literature review

Metacognitive strategies in translation. Research on metacognitive strategies in translation has evolved significantly since the pioneering work of Krings (1986) and Lörcher (1991). These

early studies established the fundamental role of metacognition in translation, identifying how translators plan, monitor, and evaluate their decision-making processes. While valuable, these initial investigations relied primarily on think-aloud protocols, which, despite their insights into translator cognition, were limited by their subjective nature and potential interference with the translation process itself (Jakobsen, 2003).

Recent theoretical developments have refined our understanding of how metacognitive strategies operate in translation. Alves and Gonçalves (2013) proposed a three-stage model of metacognitive processing in translation: problem identification, analysis, and resolution. This framework has proven particularly useful for understanding how translators navigate complex texts, though its application to specialised translation contexts remains underexplored. Risku (2014) further developed this model by emphasising the dynamic nature of metacognitive control, suggesting that translators continuously adjust their strategies based on text complexity and task demands.

The relationship between expertise and metacognitive strategy use has emerged as a crucial area of investigation. Studies by Shreve (2006a) and Jääskeläinen (2010) demonstrated that professional translators exhibit more sophisticated metacognitive control compared to novices, particularly in their ability to recognise and address translation problems efficiently. However, as Mellinger (2019) notes, the specific mechanisms through which expertise influences metacognitive strategy deployment remain incompletely understood, especially in specialised translation contexts.

Translation expertise and cognitive processing. The development of translation expertise has been conceptualised through various theoretical frameworks, with the dual-process model of cognition providing particularly valuable insights. This model, as applied to translation by Shreve (2006b) and elaborated by Deckert (2019), distinguishes between automatic and controlled processing in translation. Professional translators typically demonstrate greater automaticity in routine tasks while maintaining the ability to engage in controlled processing when confronted with complex challenges.

Empirical research has revealed significant differences in how novice and expert translators allocate cognitive resources. Alves (2015) found that professionals exhibit more efficient problem-solving strategies, characterised by faster problem identification and more systematic approaches to resolution. These findings align with broader research on expertise in cognitive psychology, suggesting that expert performance involves not just accumulated knowledge but also qualitatively different approaches to problem-solving (Togato et al., 2022).

The translation of academic texts presents particular challenges that illuminate the role of expertise in cognitive processing. Studies by Peterlin (2014) and Ayomi et al. (2020) have shown that academic translation requires sophisticated handling of complex terminology and rhetorical structures. However, research specifically examining how expertise influences metacognitive strategy use in academic translation remains limited, representing a significant gap in current understanding.

Translation process research methods. The investigation of translation processes has been transformed by methodological advances that enable more objective examination of translator behaviour. Keystroke logging, pioneered in translation research by Jakobsen (2003) and refined by subsequent researchers (Carl and Kay, 2011; Göpferich and Jääskeläinen, 2009), provides detailed temporal data about text production processes. This

approach offers valuable insights into pausing patterns, revision behaviours, and overall translation workflows.

Recent developments in data visualisation have enhanced our ability to analyse and interpret translation process data. Particularly noteworthy is the application of flow visualisation techniques to translation research (Baker and Lorenzi, 2020; Park et al., 2019). These methods help reveal patterns in cognitive resource allocation that might not be apparent through traditional analytical approaches.

However, as Carl (2021) emphasises, technological tools must be integrated thoughtfully into research designs, with careful consideration of their capabilities and limitations. The challenge lies not just in collecting detailed process data but in developing theoretical frameworks that can meaningfully interpret this information in the context of translator cognition and expertise development.

Theoretical framework for the current study. Drawing together these strands of research, this study adopts an integrated theoretical framework that combines metacognitive theory, the dual-process model of cognition, and contemporary approaches to translation process research. This framework acknowledges the complex interplay between automatic and controlled processes in translation while recognising the crucial role of metacognitive strategies in managing these processes.

Metacognitive theory, as defined by Flavell (1976), refers to “cognition about cognition,” emphasising individuals’ self-regulatory abilities in cognitive activities through planning, monitoring, and evaluating (Alves and Gonçalves, 2013; Flavell, 1976). In translation studies, metacognition involves a translator’s ability to effectively plan, monitor, and evaluate their translation strategies (Krings, 1986; Lörscher, 1996). This awareness enhances translators’ adaptability to various text types and challenges, ultimately improving the quality of their work. Professional translators typically demonstrate a higher level of metacognitive regulation, effectively identifying translation challenges, flexibly adjusting strategies, and promptly correcting errors when encountered (Jääskeläinen, 2010; Shreve, 2006a). Scholars describe the metacognitive stages of translation as a dynamic interplay that includes problem identification, problem analysis, and problem-solving (Alves and Gonçalves, 2013; Jakobsen, 2017; Mellinger, 2019; Risku, 2014).

The dual-process model of cognition, initially developed in psychology, categorises cognitive processes into two main types: automatic and controlled (Deckert, 2019; Shreve, 2006b; Uleman and Bargh, 1989; Wason and Evans, 1974). Automatic processes rely on experience and proficiency, enabling professional translators to quickly recognise language structures and execute translation tasks with minimal conscious effort (Shreve, 2006a). In contrast, controlled processes are slower and demand more cognitive resources, requiring conscious attention to address novel or complex problems (Deckert, 2019). Professional translators are able to flexibly switch between these two modes of processing, dynamically adjusting their cognitive investment according to text difficulty and task demands (Togato et al., 2022).

Translation process models further enhance the understanding of how translators navigate between these cognitive strategies. Such models provide a structured approach to comprehending the sequence of cognitive and metacognitive actions involved in translation (Jääskeläinen, 1993; Krings, 1986). They typically delineate phases such as comprehension, planning, and production, each characterised by specific demands that require various metacognitive strategies. The integration of these theoretical frameworks allows for a deeper exploration of the cognitive

mechanisms underlying translation, elucidating the factors that contribute to effective and nuanced translation practices.

The adoption of these theoretical frameworks is particularly appropriate for this study because academic translation tasks are characterised by high complexity and specialisation. Translators are required not only to possess strong linguistic competence but also to demonstrate advanced metacognitive regulation and flexible cognitive resource allocation. By combining metacognitive theory and dual-process theory, this study aims to provide a more comprehensive account of the differences in strategy selection, resource allocation, and their evolution between professional and student translators during the translation process.

Through the analysis of behavioural data (such as thinking time, writing time, and resource consultation) across different translation stages, this study explores the specific manifestations of metacognitive regulation and dual-process processing in actual translation activities. The findings are expected to enrich the theoretical foundation of cognitive translation studies and provide theoretical support for translator training.

Research methods

Participants. This study employed a stratified sampling approach to investigate metacognitive strategies in translation, recruiting 60 participants divided equally between professional translators and graduate students in translation studies. The sample size was determined through a priori power analysis (G*Power 3.1), which indicated that 29 participants per group would achieve adequate statistical power ($d = 0.5$, $\alpha = 0.05$, $1 - \beta = 0.80$) for independent samples *t*-tests. To account for potential data loss, the sample size was increased to 30 participants per group.

The professional translators ($n = 30$) ranged in age from 32 to 45 years ($M = 38.6$, $SD = 3.8$), with translation experience spanning 5 to 15 years ($M = 8.4$, $SD = 2.7$). Most held master’s degrees in Translation (70%) or Linguistics (30%), and all demonstrated high English proficiency with TOEIC scores between 900 and 990 ($M = 945$, $SD = 25.3$). Their professional standing was further evidenced by certifications from recognised bodies such as CIOL (40%) and ATA (35%). The recruitment of professional translators focused on ensuring representativeness of the academic translation sector, with participants drawn from university translation centres (40%), publishing houses specialising in academic content (35%), and freelance professionals with substantial academic translation portfolios (25%). This distribution reflects the typical employment patterns within the specialised academic translation field.

The student group comprised graduate students enrolled in MA Translation programs, aged 23–28 years ($M = 25.3$, $SD = 1.6$), with 1–2 years of translation coursework experience. While their TOEIC scores (ranging from 850 to 920, $M = 875$, $SD = 18.7$) were lower than the professional group, all met the minimum requirement for participation in academic translation tasks. The gender distribution was comparable between groups, with female translators comprising 65% of professionals and 70% of students.

To ensure comprehensive understanding of participant backgrounds and control for potential confounding variables, we collected additional information about their domain expertise in academic fields, experience with computer-assisted translation tools, and typical translation workflows. This information proved valuable in contextualising the observed differences in translation strategies between the two groups.

Materials and task design. The translation tasks were carefully selected from academic articles published in peer-reviewed

Chinese journals. Two introductory sections, each approximately 1,000 characters in length, were chosen based on their representativeness of academic discourse and comparable complexity levels. The selection process involved multiple stages of validation to ensure task equivalency.

Initial linguistic analysis using the Stanford Chinese Parser and LingKit confirmed comparable levels of textual complexity between the selected passages. Specifically, the texts showed similar patterns in syntactic complexity ($M1 = 8.4$, $M2 = 8.6$), term density ($M1 = 15\%$, $M2 = 14.8\%$), mean T-unit length ($M1 = 24.5$, $M2 = 25.1$), and subordinate clause ratios ($M1 = 0.45$, $M2 = 0.43$). These metrics provided quantitative evidence for the structural equivalence of the source texts.

Expert validation formed the second stage of material preparation. A panel of five senior reviewers, including three translation experts and two linguistics professors, evaluated the texts using a five-point scale. Their assessment covered multiple dimensions: topic relevance, difficulty level, stylistic consistency, and terminology usage. Statistical analysis of their ratings revealed no significant differences between the texts ($p > 0.05$), supporting their suitability for comparative research purposes.

The final validation stage involved pilot testing with five participants (two students, three professionals). This practical evaluation yielded comparable metrics across both texts: completion times (Text 1: $M = 112$ min; Text 2: $M = 108$ min), error rates (Text 1: $M = 3.8\%$; Text 2: $M = 3.6\%$), and perceived difficulty ratings (Text 1: $M = 3.7/5$; Text 2: $M = 3.6/5$). These results further confirmed the equivalence of the translation tasks.

Procedure. The main study implemented a carefully structured protocol for data collection. Drawing from pilot results and previous research (Göpferich and Jääskeläinen, 2009), each translation task was allocated 120 min. Sessions were scheduled in the morning and afternoon, separated by a 15-min break—a duration informed by cognitive load research (Brummelhuis and Trougakos, 2014) to minimise fatigue effects.

Participants were provided with standardised instructions and access to online resources typically available in professional translation settings. They were encouraged to maintain their natural translation workflows while using the provided computer setup, which included Inputlog 8.0 for keystroke logging.

Data collection and analysis. The study employed a multi-layered approach to data collection and analysis. Inputlog 8.0 recorded detailed keystroke data throughout the translation process, capturing query time (consultation of external resources), thinking time (periods without keyboard or mouse activity), writing time (active text production), pause patterns, and revision behaviours. This granular data collection enabled comprehensive analysis of participants’ metacognitive strategies during translation.

Data preprocessing involved several stages of refinement. Outliers were identified and treated using the interquartile range method, followed by pause time normalisation to account for individual differences in typing speed. The resulting dataset provided a clean foundation for subsequent statistical analyses.

The analytical framework incorporated both quantitative and qualitative elements. Statistical analyses included normality testing (Shapiro-Wilk) and homogeneity of variance assessment (Levene’s test) as prerequisites for group comparisons. Independent samples t-tests were then conducted to examine differences between professional and student translators, with effect sizes calculated using Cohen’s d to assess the practical significance of observed differences.

To visualise the complex patterns of metacognitive strategy deployment, we generated diagrams using Python’s matplotlib and network libraries. These visualisations proved particularly effective in illustrating the distribution and flow of cognitive activities across the three translation stages: problem identification, analysis, and resolution, revealing distinct patterns between professional and student translators.

Translation quality assessment followed Waddington’s (2001) framework, examining accuracy, fluency, terminology usage, and stylistic appropriateness. Specifically, this holistic assessment model employs a five-point scale (0–4) for each dimension, with detailed descriptors for each level. Accuracy was evaluated by comparing source and target texts for meaning preservation; fluency through assessment of grammatical correctness and readability; terminology usage through consistency and appropriateness; and stylistic appropriateness through register and genre conventions adherence.

Two independent raters with expertise in academic translation evaluated each translation, with an inter-rater reliability coefficient of 0.87 (Cohen’s kappa), indicating strong agreement. Discrepancies were resolved through discussion to reach consensus scores. This evaluation provided crucial context for interpreting the process data, allowing us to correlate different patterns of metacognitive strategy use with translation outcomes. All statistical analyses were performed using R 4.1.0 and Python 3.8, maintaining a significance level of $\alpha = 0.05$ throughout the study.

Results
Metacognitive strategy differences between groups. Our analysis revealed distinct patterns in metacognitive strategy use between professional and student translators. To systematically present these differences, we first provide an overview of temporal distribution patterns in Table 1, followed by statistical comparisons of key temporal metrics in Table 2.

Table 1 presents the overall temporal distribution of translation activities, showing how participants allocated their time across three main cognitive activities: thinking, writing, and resource consultation. As shown in this table, professional translators demonstrated notably shorter thinking times ($M = 1696.33$ s, $SD = 326.59$) compared to students ($M = 2933.98$ s, $SD = 852.03$). Conversely, professionals allocated more time to writing ($M = 4398.53$ s, $SD = 445.88$) than students ($M = 3226.48$ s, $SD = 753.89$), suggesting different approaches to text production.

Query time patterns, also presented in Table 1, showed a more nuanced distinction. Professionals spent marginally more time on external resource consultation ($M = 1152.90$ s, $SD = 113.59$) compared to students ($M = 1044.57$ s, $SD = 83.30$), suggesting different approaches to information seeking during translation.

Table 1 Temporal distribution of translation activities between professional and student translators.		
Activity type	Professional translators	Student translators
Thinking time	1696.33 s (326.59)	2933.98s (852.03)
Writing time	4398.53 s (445.88)	3226.48s (753.89)
Query time	1152.90 s (113.59)	1044.57s (83.30)
Total task time	7247.76 s (572.38)	7205.03s (648.25)
Writing-to-thinking ratio	2.59 (0.41)	1.10 (0.28)
This table presents mean time (in seconds) spent in each cognitive activity with standard deviations in parentheses. Higher writing-to-thinking ratios indicate more efficient cognitive processing.		

Table 2 Independent samples T-Test results for key temporal metrics.

Variable	Professional mean (SD)	Student mean (SD)	t(58)	p value	Cohen's d
Thinking time	1696.33 (326.59)	2933.98 (852.03)	9.521	<0.001	1.89
Writing time	4398.53 (445.88)	3226.48 (753.89)	9.499	<0.001	1.87
Query time	1152.90 (113.59)	1044.57 (83.30)	5.792	<0.001	1.09
Mean pause duration	4.82 (0.95)	8.37 (1.28)	15.634	<0.001	3.12
Pause frequency	352.41 (41.23)	350.57 (39.86)	0.228	0.820	0.05
Writing-to-thinking ratio	2.59 (0.41)	1.10 (0.28)	22.305	<0.001	4.28

This table presents detailed statistical comparison of the three primary temporal metrics, including t-values, degrees of freedom, significance levels, and effect sizes (Cohen's d).

Table 3 Statistical comparison of identification stage metrics.

Variable	Professional mean (SD)	Student mean (SD)	t(58)	p value	Cohen's d
Thinking time	985.44 (201.64)	1723.53 (412.86)	15.873	<0.001	2.32
Pause frequency	142.37 (23.16)	148.22 (25.71)	1.043	0.298	0.24
Mean pause duration	6.92 (1.21)	11.63 (2.39)	18.247	<0.001	2.49
Writing-to-thinking ratio	0.41 (0.08)	0.22 (0.05)	-15.398	<0.001	2.83

This table presents comparative statistics on time allocation and cognitive effort during the initial translation stage, showing significant differences in processing efficiency between groups.

To determine the statistical significance of these observed differences, Table 2 presents the results of independent samples *t*-tests performed for the three key metrics. The statistical comparison confirms that the differences in thinking time ($t(58) = 9.521$, $p < 0.001$, $d = 1.89$), writing time ($t(58) = -9.499$, $p < 0.001$, $d = 1.87$), and query time ($t(58) = -5.792$, $p < 0.001$, $d = 1.09$) are all statistically significant, with large effect sizes for the first two metrics.

Of particular note in Table 2 is the statistical comparison of Mean Pause Duration between professionals ($M = 4.82$ s, $SD = 0.95$) and students ($M = 8.37$ s, $SD = 1.28$), $t(58) = 15.634$, $p < 0.001$, $d = 3.12$, suggesting more automatised processing among experienced translators.

Evolution of strategy use across translation stages. To understand how metacognitive strategies evolve throughout the translation process, we analysed temporal patterns across three distinct translation stages. This analysis revealed significant differences in strategy adaptation between professional and student translators.

Table 3 presents statistical comparisons of key metrics during the problem identification stage. During this initial stage, both groups showed high cognitive engagement, but professionals demonstrated more efficient processing with significantly lower thinking times.

As shown in Table 3, professional translators exhibited significantly shorter thinking times during the identification stage ($M = 985.44$ s, $SD = 201.64$) compared to students ($M = 1723.53$ s, $SD = 412.86$), with a large effect size ($d = 2.32$). While pause frequency showed no significant difference between groups ($p = 0.298$), professionals' Mean Pause Duration was substantially shorter ($M = 6.92$ s, $SD = 1.21$) than students' ($M = 11.63$ s, $SD = 2.39$). The writing-to-thinking ratio during this initial stage was also significantly higher for professionals ($M = 0.41$, $SD = 0.08$) than for students ($M = 0.22$, $SD = 0.05$), indicating more efficient text production even during the problem identification phase.

Tables 4 and 5 provide a detailed analysis of processing efficiency during the problem analysis stage, comparing multiple metrics between the two translator groups. This second stage revealed substantial differences in how professionals and students processed and resolved translation challenges.

The analysis stage data in Table 4 shows that professional translators maintained shorter thinking times ($M = 479.28$ s, $SD = 203.86$) compared to students ($M = 1130.05$ s, $SD = 290.99$), $t(58) = 12.740$, $p < 0.001$, $d = 2.58$. Similarly, professionals had significantly shorter pause durations ($M = 4.25$ s, $SD = 0.87$) compared to students ($M = 9.88$ s, $SD = 1.95$), $t(58) = 19.346$, $p < 0.001$, $d = 3.72$. The writing-to-thinking ratio increased for professionals during this stage ($M = 1.86$, $SD = 0.52$) compared to their performance in the identification stage, while students showed minimal improvement ($M = 0.79$, $SD = 0.19$).

Comparing the data across Tables 3 and 4, we can observe that both groups showed decreases in thinking time from identification to analysis stages, but professionals demonstrated a more substantial proportional reduction (51.4% decrease compared to students' 34.4% decrease). This suggests greater flexibility in cognitive resource allocation among professional translators.

Professional translators showed significantly higher writing-to-thinking ratios ($M = 5.10$, $SD = 0.75$) compared to students ($M = 2.85$, $SD = 0.63$), $t(58) = -16.061$, $p < 0.001$, $d = 3.28$. This difference suggests that professional translators have developed more automated translation processes, enabling faster text production with less cognitive effort.

Visualisation of cognitive resource distribution. To further illustrate the patterns of metacognitive strategy deployment, we analysed the distribution of cognitive resources using flow visualisation techniques. Table 6 presents a comparison of resource distribution coefficients between professional and student translators, highlighting significant differences in cognitive resource management.

The diagrams (Figs. 1 and 2) provide visual representation of cognitive resource allocation across translation stages. Professional translators exhibited more concentrated flows between stages, with thicker connections indicating efficient resource transfer. The average flow intensity between stages was significantly higher for professionals ($M = 2691.20$, $SD = 342.15$) compared to students ($M = 2018.40$, $SD = 298.73$), $t(58) = 10.837$, $p < 0.001$, $d = 2.12$.

Figure 1 illustrates how professional translators maintained relatively consistent cognitive engagement across stages, with the

Table 4 Processing efficiency comparison during analysis stage.					
Variable	Professional mean (SD)	Student mean (SD)	t(58)	p value	Cohen's d
Thinking time	479.28 (203.86)	1130.05 (290.99)	12.740	<0.001	2.58
Pause frequency	112.83 (18.43)	114.36 (16.91)	0.427	0.670	0.09
Mean pause duration	4.25 (0.87)	9.88 (1.95)	19.346	<0.001	3.72
Writing-to-thinking ratio	1.86 (0.52)	0.79 (0.19)	−13.652	<0.001	2.75

This table presents comparative metrics for the analysis stage, including pause duration, processing time, and efficiency ratios between professional and student translators.

Table 5 Translation strategy metrics during resolution stage.					
Variable	Professional mean (SD)	Student mean (SD)	t(58)	p value	Cohen's d
Thinking time	231.61 (97.52)	480.40 (148.18)	10.253	<0.001	1.98
Pause frequency	97.21 (12.85)	95.99 (14.26)	−0.451	0.653	0.09
Mean pause duration	2.38 (0.53)	5.00 (1.13)	14.832	<0.001	2.97
Writing-to-thinking ratio	5.10 (0.75)	2.85 (0.63)	−16.061	<0.001	3.28

This table presents comparative data on strategy adaptation during the resolution stage, with metrics on writing speed, pause patterns, and cognitive efficiency between groups.

Table 6 Comparison of cognitive resource distribution coefficients between groups.					
Metric	Professional mean (SD)	Student mean (SD)	t(58)	p value	Cohen's d
Flow intensity	2691.20 (342.15)	2018.40 (298.73)	10.837	<0.001	2.12
Variation coefficient	0.18 (0.04)	0.31 (0.07)	12.429	<0.001	2.32
Transition efficiency	0.86 (0.09)	0.62 (0.11)	12.053	<0.001	2.41
Resource distribution balance	4.35 (0.67)	2.18 (0.53)	17.893	<0.001	3.57
Strategy adaptation index	8.75 (1.42)	5.21 (0.98)	14.371	<0.001	2.89

This table presents coefficients of variation in resource allocation, flow intensity measures, and transition efficiency metrics across translation stages for both groups.

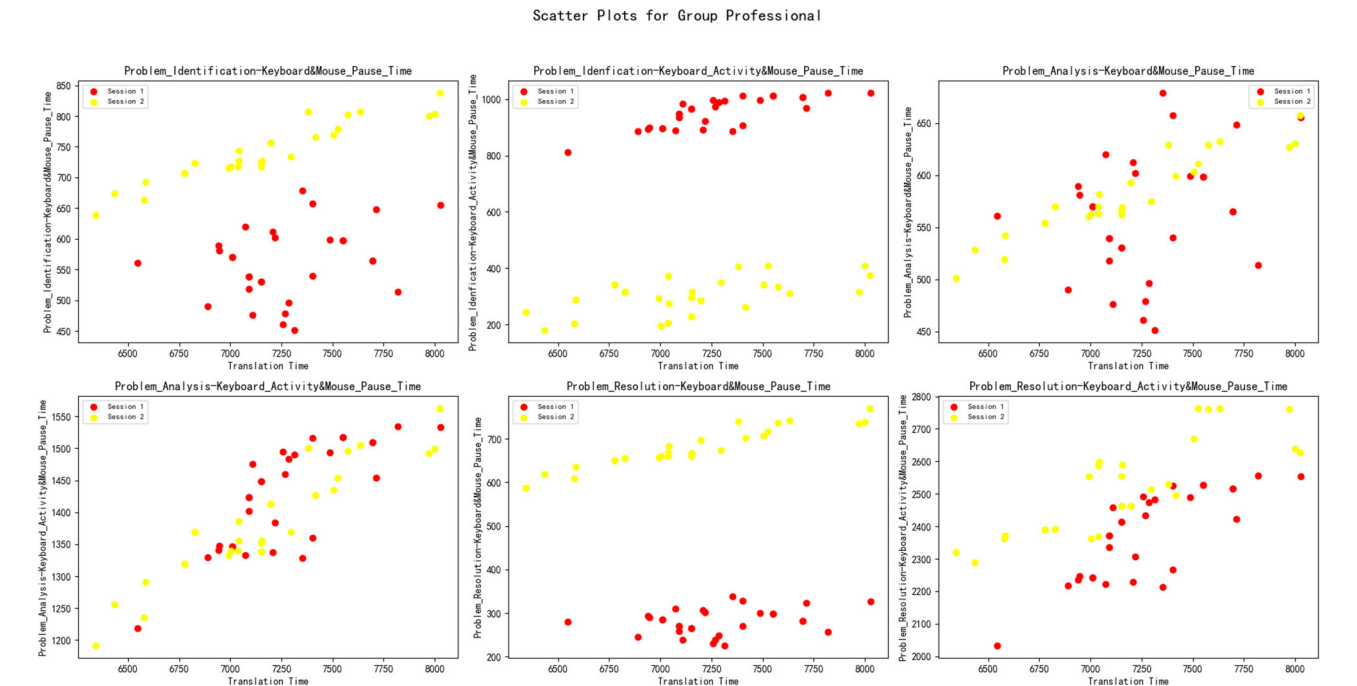


Fig. 1 Cognitive resource distribution of professional translators. *Note: This diagram illustrates the flow of cognitive resources across three translation stages (problem identification, analysis, and resolution) for professional translators. Width of paths represents resource intensity; node size indicates time allocation. Coefficient of variation = 0.18 indicates consistent engagement across stages.

Scatter Plots for Group Student

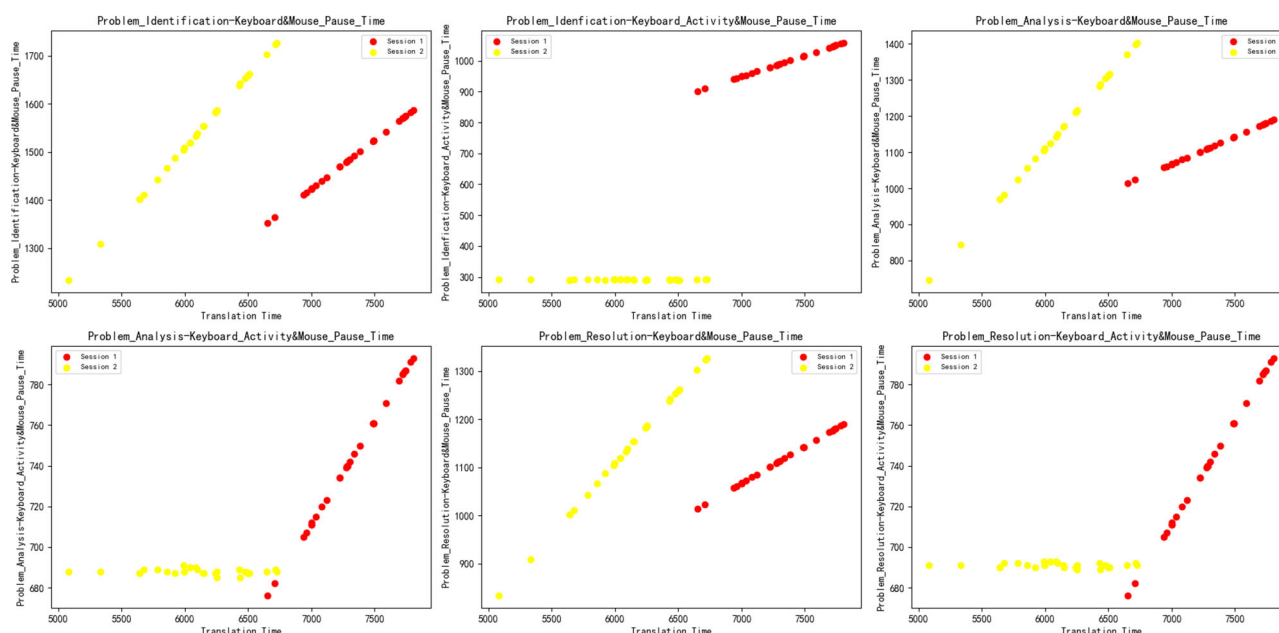


Fig. 2 Cognitive resource distribution of student translators. *Note: This diagram shows cognitive resource distribution for student translators. Compared to Fig. 1, the wider variance in path widths (coefficient of variation = 0.31) demonstrates more variable resource allocation, particularly during transitions between stages.

width of flow paths showing only moderate variation (coefficient of variation = 0.18). In contrast, Fig. 2 reveals more variable resource allocation among students (coefficient of variation = 0.31), particularly during transitions between stages. The visualisation analysis also revealed differences in the pattern of cognitive resource redistribution. Professional translators showed more dynamic adaptation of strategy use, evidenced by the balanced distribution of flow intensities across different pathways. Student translators, however, demonstrated more rigid patterns, with certain pathways dominating their cognitive resource allocation.

These visualisations complement the statistical findings by illustrating the qualitative differences in how translators at different expertise levels manage cognitive resources. The patterns observed support the quantitative analysis while providing additional insights into the dynamic nature of metacognitive strategy deployment during translation.

Discussion

Summary of key findings. This study set out to investigate three key research questions regarding metacognitive strategy use in academic translation. Our findings provide clear evidence of distinct patterns between professional and student translators. First, regarding metacognitive strategy patterns, professionals demonstrated significantly shorter thinking times ($M = 1696.33$ s vs $M = 2933.98$ s) and higher writing-to-thinking ratios (2.59 vs 1.10), indicating more efficient cognitive processing. Second, the evolution of strategies across translation stages revealed that professionals exhibited greater flexibility in cognitive resource allocation, with a 51.4% reduction in thinking time from identification to analysis stages, compared to students' 34.4% reduction. Third, our analysis of cognitive resource distribution showed that professionals maintained more consistent engagement across stages (coefficient of variation = 0.18) compared to students' more variable patterns (coefficient of variation = 0.31).

Interpretation of results in context. These findings both confirm and extend previous research on translator cognition. The marked difference in thinking times aligns with earlier studies suggesting expertise-related processing advantages (Deckert, 2019; Shreve, 2006a). However, our results reveal a more nuanced picture than previously documented. While the shorter thinking times among professionals were expected, the maintenance of high writing-to-thinking ratios across all translation stages was not anticipated. This finding suggests that professional expertise manifests not merely in faster processing but in qualitatively different approaches to cognitive resource management.

An unexpected finding emerged in the pattern of resource consultation. Contrary to the common assumption that experienced translators would require less external support, professionals actually spent marginally more time on resource consultation ($M = 1152.90$ s vs $M = 1044.57$ s). This finding challenges the simplistic view that expertise necessarily reduces dependence on external resources, suggesting instead that professional translators may engage more strategically with reference materials.

Theoretical implications. The present study provides empirical support for the dual-process model of cognition in translation, demonstrating that professional translators exhibit not just shorter thinking times but more efficient transitions between translation stages. These findings extend beyond previous research (Togato et al., 2022) by showing that translation expertise involves dynamic switching rather than a simple shift from controlled to automatic processing. The temporal analysis of translation stages further refines our understanding of metacognitive strategy evolution, revealing that professional expertise is characterised by qualitatively distinct approaches to problem-solving and resource allocation.

Our findings particularly advance the theoretical understanding of how metacognitive regulation develops in translation expertise. The observed patterns of cognitive resource allocation

among professionals corroborate the notion that expertise is marked by both efficiency and flexibility, supporting but also extending the three-stage model of metacognitive processing (Alves and Gonçalves, 2013). Our findings are consistent with prior studies that emphasise the role of metacognitive regulation in expert translation performance (Jääskeläinen, 2010; Shreve, 2006a). Moreover, the use of keystroke logging and process visualisation in this study provides new empirical evidence supporting theoretical claims about the dynamic nature of translator cognition (Carl and Kay, 2011; Risku, 2014).

Practical applications. The clear differences in cognitive resource allocation between professional and student translators have direct implications for translator education. Training programs should focus on developing students' abilities in rapid problem identification, systematic analysis, and adaptive strategy use. The balanced distribution of cognitive effort observed among professionals provides a model for designing exercises that foster both automaticity and metacognitive awareness. Additionally, the integration of process data and visualisation tools, such as keystroke logging and diagrams, can offer valuable feedback to trainees, helping them monitor and refine their translation strategies in real time.

At the same time, the results challenge some assumptions in the literature regarding novice translators. While students demonstrated less efficient resource allocation and more variable engagement across translation stages, their performance also revealed areas of strategic awareness, particularly in the use of external resources. This suggests that metacognitive development is a gradual process, with novice translators exhibiting emerging forms of self-regulation that can be further cultivated through targeted training (Mellinger, 2019).

Practical applications. The clear differences in cognitive resource allocation between professional and student translators have direct implications for translator education. Training programs should focus on developing students' abilities in rapid problem identification, systematic analysis, and adaptive strategy use. The balanced distribution of cognitive effort observed among professionals provides a model for designing exercises that foster both automaticity and metacognitive awareness. Additionally, the integration of process data and visualisation tools, such as keystroke logging and diagrams, can offer valuable feedback to trainees, helping them monitor and refine their translation strategies in real time.

Conclusion

This study advances our understanding of how translation expertise shapes metacognitive strategy use, particularly in the demanding context of academic translation between Chinese and English. By integrating cognitive process research with empirical keystroke data, we demonstrate that expertise manifests in fundamentally different, more adaptive approaches to cognitive resource management. Our findings reveal that professional translators do not simply work faster—they demonstrate a dynamic balance between automatic and controlled processes, responding flexibly to complex linguistic and conceptual challenges.

Several methodological considerations and limitations warrant attention. While keystroke logging provided detailed temporal data, it cannot fully capture all aspects of cognitive activity—periods of inactivity may reflect various forms of engagement beyond thinking. The abstraction inherent in flow visualisations, though useful for group-level analysis, may obscure individual differences and the complexity of real-world translation

processes. Our focus on academic texts and reliance on keystroke logging as the primary process measure may limit the generalisability of the findings.

Looking ahead, several promising research directions emerge. Future studies should consider triangulating keystroke data with retrospective interviews or screen recordings to obtain a more comprehensive picture of translator cognition. Longitudinal research could track the development of metacognitive strategies as translators gain expertise, while exploring the potential of technology-assisted training through real-time feedback. Additionally, expanding the scope to include different text types and translation contexts would help determine the generalisability of these results and uncover text-specific patterns in metacognitive strategy use.

Our results contribute significantly to the international discourse on translation cognition by refining theoretical models of metacognitive regulation and dual-process processing. The implications reach beyond academic translation—in an era where global communication increasingly depends on high-quality translation, understanding the cognitive foundations of expert performance is critical. This study provides a foundation for developing evidence-based translator training programmes that foster not only technical proficiency but also metacognitive awareness and strategic flexibility—qualities essential for navigating the demands of a rapidly changing translation landscape.

Data availability

All data generated or analysed during this study are available from the corresponding author on reasonable request.

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Author contributions

Dahui Dong: methodology; data processing; writing review & editing. Meng-Lin Chen: draft writing, data analysis, and visualisation; grant application and funding.

Competing interests

The authors declare no competing interests.

Ethical approval

The study was approved by the National Cheng Kung University Human Ethics Committee (NCKU HREC) on September 6, 2021 (Approval No. NCKU HREC-110-217-2). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The scope of approval covered the recruitment of professional and student translators, collection of keystroke logging data, and analysis of translation processes.

Informed consent

Written informed consent was obtained from all individual participants included in the study. The consent was obtained by the principal investigator prior to data collection in March 2022. All participants were fully informed that their anonymity would be assured, that the research aimed to investigate metacognitive strategies in translation processes, and that their keystroke logging data would be used for academic research purposes only. They were also informed that participation was voluntary and they could withdraw at any time without consequences. The scope of consent covered participation in the translation task, collection and analysis of keystroke logging data, and the use of anonymized data in academic publications.

Additional information

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