FLIGHT EXPERIENCE AND MENTAL REPRESENTATIONS OF SPACE

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Spatial skills are critical for flight safety. The current study investigated whether increased flight experience as a pilot was associated with improved spatial skills, and in particular, the ability to form a mental representation of a novel virtual environment. Pilots completed small-scale spatial ability tasks, travelled along four routes in a virtual environment, and then completed two tests that assessed memory for the locations of landmarks in the environment. Pilots with more flight experience did not have more accurate mental representations of the environment than individuals with less flight experience. Increased flying experience was, however, linked to better performance on a perspective-taking test. Perspective taking has been proposed as central to navigation awareness during flight, and the current data suggest it improves with experience.

Successful navigation of an aircraft is a complex cognitive skill that demands pilots plan a route from point A to point B and be able to quickly plan alternate routes in the event of an emergency (Transport Canada, 2010). The foundation for such wayfinding is an ongoing understanding of the plane's current location relative to landmarks and other objects during flight. Gibb, Ercoline, and Scharff (2011) estimate that spatial disorientation, a situation in which a pilot mistakes the plane's location, motion, and/or attitude, accounts for 25-33% of all aviation accidents. In many cases, the pilot unknowingly makes this misjudgement and remains unaware of the mistake until it is too late. Gibb et al. also argue that mishaps attributed to spatial disorientation, which are underreported, have the highest fatality rate in comparison with other causes of crashes, indicating the critical importance of spatial cognition for flight safety.

It is well-established that spatial skills are not fixed abilities and can be improved through training in the laboratory (see Uttal et al., 2013 for a meta-analysis), but evidence that flight experience, in particular, can lead to improved spatial skills remains mixed (Dror, Kosslyn, & Waag, 1993; Sutton, Buset, & Keller, 2014). For instance, Dror et al. found that military pilots performed better than non-pilot controls on a mental rotation task but showed no difference on judgements of categorical spatial relations or mental image scanning. Furthermore, whether the mental rotation finding is attributable to spatial skills acquired in flying is unclear, as small-scale spatial abilities are only partially related to performance on large-scale navigation tasks (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006). On the other hand, Sutton et al. (2014) found that early-career civil aviation pilots formed more accurate cognitive maps of a novel virtual environment than non-pilot controls matched to the pilots on age and video game experience. These findings suggest that the spatial skills pilots acquire transfer to other, non-flight, navigation tasks and result in more accurate mental representations of the environment.

A cognitive map is a map-like mental representation of the configuration of landmarks in an area, often described as a mental "birds-eye-view" that is orientation independent (O'Keefe & Nadel, 1978; Tolman, 1948), and Sutton et al. (2014) suggested that multiple aspects of flight may improve cognitive mapping skills. For instance, the unique aerial views and/or the demands of constantly updating the aircraft's spatial position during flight may facilitate encoding the environment in memory as a cognitive map. In addition, assessments for pilot licensure include a requirement for candidates to assume a new heading and anticipate the locations of objects along the new path (Transport Canada, 2010), a skill greatly facilitated by having a mental map of the environment. Quick calculation of a detour using a map-like memory of an area requires an understanding of the current positions of objects relative to the plane and to each other, and the ability to mentally transform those relationships to correspond to a new heading, a process known as perspective taking (Thurstone, 1950). According to Aretz (1991), perspective taking is central to a pilot's navigation awareness during flight, and when combined with pilots' unique aerial viewpoint akin to a map, perspective-taking practice may lead to improved precision both in the storage and retrieval of cognitive maps in memory.

The current study extended the findings of Sutton et al. (2014) by investigating whether cognitive map accuracy and/or perspective taking improve with increasing hours of flight experience. Pilots explored a virtual environment, *Silcton*, via four separate routes and afterwards were tested for their ability to combine the routes into a single map of the environment. We predicted that pilots with more flight hours would form more accurate cognitive maps of Silcton than pilots who had fewer flight hours. In addition, we predicted that more hours would be associated with better memory of the routes travelled in Silcton. Because we hypothesized that perspective taking skills were a potential mechanism facilitating cognitive map encoding and retrieval in individuals with flight experience, a paper-and-pencil perspective-taking task was also administered in order to assess the association of perspective taking with flight hours and cognitive mapping skills. We expected that, as with the measures of Silcton, perspective taking would improve with increasing flight experience.

Method

Participants

Forty-two students (36 males, 6 females, mean age = 20.48) with at least one hour of flight experience were recruited from The University of Western Ontario. Participants were in the early stage of their careers with a varying number of flight hours (M = 75.79, SD = 70.94). Twenty-three participants (20 males, 3 females; M age = 20.48, SD = 3.94, range = 17 - 37) held a Private Pilot Licence or higher (e. g., Commercial Pilot Licence) and 19 had not yet obtained a licence (16 males, 3 females; M age = 20.47, SD = 3.34, range = 18 - 32). Some participants received $15 in compensation for participating in the study and others received course credit. Data for every participant (N = 42) are reported for all measures, except the same route and different route direction estimation tasks and the map building task, where N = 41 due to a technical error. The study was approved by the University of Western Ontario Non-Medical Research Ethics Board.

Materials and Procedure

After providing written informed consent, participants completed a demographic questionnaire where information on hours of flight experience, licences and ratings obtained, and GPS usage during flight was collected. Next, participants completed the Santa Barbara Sense of Direction scale (SBSOD; Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002), which assessed self-reported spatial abilities. After the SBSOD, participants completed the paper-and-pencil-based Spatial Orientation Test (SOT; Hegarty & Waller, 2004), a measure of perspective-taking ability where participants are required, while looking at a static array of objects on the page, to assume an imagined heading direction in the array and indicate the direction of another object in the array. Next, participants completed a spatial n-back test of spatial working memory. Note that of these tasks, only data from the demographic questionnaire and the SOT are presented in this paper.

After the small-scale spatial tasks, participants completed the virtual environment task using the Silcton environment (Weisberg, Schinazi, Newcombe, Shipley, & Epstein, 2013) presented on a 15.6” laptop (Samsung R525, Samsung Electronics, Suwon, South Korea) running Windows 7 64-bit with an AMD Phenom II Quad-Core N970 2.2 GHz Processor and an AMD Radeon HD 6600M Graphics card (Advanced Micro Devices, Sunnyvale, CA). First, participants familiarized themselves with the controls (arrow keys and mouse) and practiced moving around in Silcton. When participants were comfortable with the controls, they were instructed that they would be exploring four different routes (2 main routes and 2 connecting routes) through the same town used for practice. They were instructed to remember the names and the locations of eight buildings marked with blue diamonds in Silcton, as the tasks that followed would test their knowledge for these buildings. Participants travelled each route from start to finish, following red arrows marked on the path, and back to start. Participants were given an unlimited amount of time to complete the travel on each route.

Immediately after traversing all four routes, participants completed a direction estimation task based on memory for Silcton (Weisberg et al., 2013) where they were asked to place the eight target buildings around the perimeter of a circle in their appropriate directions from given heading directions. For instance, on one item, participants were instructed to imagine they were standing at Harris Hall facing the Batty House. From this heading, they positioned the eight buildings to indicate their directions relative to the imagined heading. This task provided measures of route and cognitive map accuracy, as participants were asked to estimate the directions of buildings on the same route (a measure of route knowledge) and buildings on different routes (a measure of map knowledge).

Participants completed a final map-building task (Weisberg et al., 2013) where they were shown a blank rectangle on the computer screen and were instructed to drag and drop bird's-eye images of the eight Silcton buildings into their appropriate locations.

Results

Means and standard deviations for all measures reported here are shown in Table 1. Paired *t* tests showed that pilots were more accurate (i.e., showed less error) at estimating directions between landmarks along the same route than across different routes, $t(40) = -8.28$, $p < .001$, and means for both estimation measures were significantly better than chance (90°), same route: $t(40) = -14.87$, $p < .001$; different routes: $t(40) = -4.28$, $p < .001$.

Table 1.
Means and Standard Deviations for Flight Hours, Spatial Orientation Test (SOT), and Silcton Measures.

			Silcton Direction Estimation Error		
	Flight hours	SOT	Landmarks on the same route	Landmarks on different routes	Silcton map building
M	75.79	21.58	64.72	81.13	.52
SD	70.94	0.07	10.88	13.27	.28

Note: SOT and direction estimation error measures are reported in absolute degrees. Accuracy on the Silcton map building task was scored using a bidimensional regression procedure resulting in an R^2 value with a potential range from 0 – 1.0.

Table 2 shows the results of two-tailed Pearson correlations. As expected, measures based on memory for Silcton were significantly correlated. Hours of flight experience was not significantly correlated with cognitive map accuracy of Silcton, as reflected in the measures of different-route direction estimation error and map building. Similarly, there was no correlation between flight experience and route knowledge on the same-route direction estimation task. Scatterplots and R^2 values for the associations between hours and same- and different-route direction estimation measures are shown in Figure 1 (panels A and C). In addition, experience was measured by dividing pilots into those holding at least a Private Pilot Licence (n = 23) or no licence (n = 19), and direction estimation error for both groups can be seen in Figures 1B and 1D. There was no significant difference between the groups on same-route direction estimation error, $t(17) = -1.75$, $p = .09$, nor on different-route estimation error, $t(17) = 0.11$, $p = .92$.

Table 2.
Pearson Correlations for Flight Hours, Spatial Orientation Test, and Silcton Measures.

	SOT	Direction estimation error: same route	Direction estimation error: different routes	Silcton map building
Flight hours	-.44**	.07	-.03	.09
SOT	-	-.10	-.04	-.07
Direction estimation error: same route	-	-	.46**	-.59***
Direction estimation error: different routes	-	-	-	-.49**

Note. * *p* < .05, ** *p* < .01, *** *p* < .001.

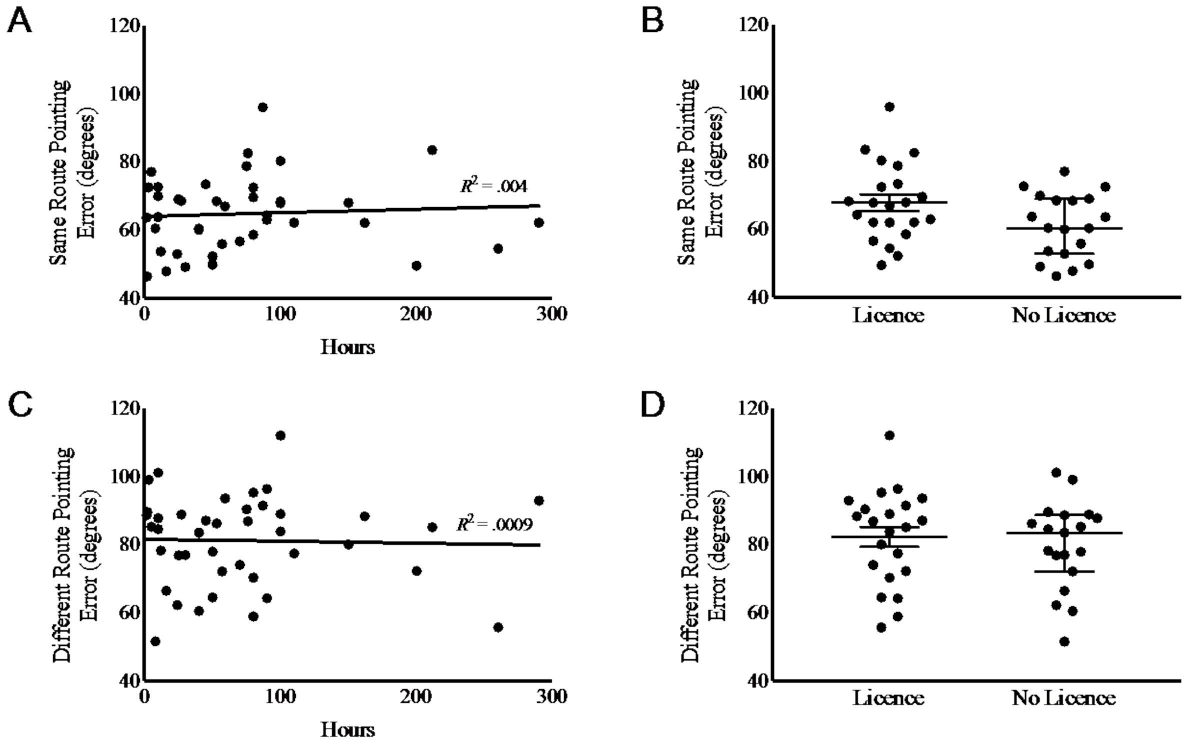

Figure 1. (A) Correlation between hours and error on same route direction estimation measure; (B) Means (center horizontal lines) and standard errors (outer horizontal lines) on the same route direction estimation measure for pilots holding at least a private pilot's licence versus those with no licence; (C) Correlation between hours and error on the different route direction estimation measure; (D) Means (center horizontal lines) and standard errors (outer horizontal lines) on the different route direction estimation measure for pilots holding at least a private pilot's licence versus those with no licence. Filled circles show individual scores.

Table 2 also shows that flight hours were significantly associated with performance on the SOT perspective-taking test, where participants with more flight experience showed lower error scores. Figure 2A shows a scatterplot of the relationship between flight hours and SOT error. A linear regression model showed that hours significantly predicted SOT error, β = -.44, p = .004, accounting for 19% of the variance in SOT performance, R^2 = .19, $F(1, 40) = 9.60$, p = .004. Figure 2B shows SOT error for pilots holding at least a private pilot's licence versus pilots with no licence. Licence holders showed significantly less error on the SOT than those without a licence, $t(18)$ = 2.99, p = .01.

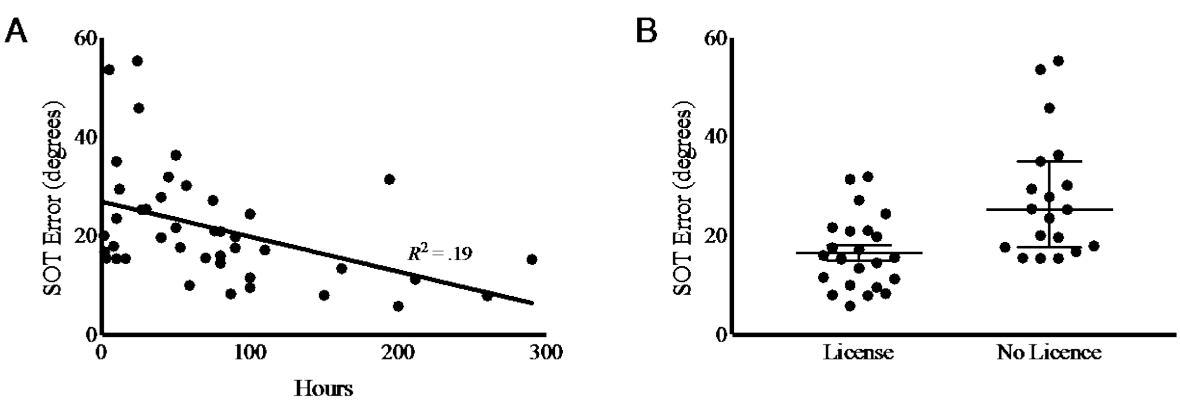

Figure 2. (A) Correlation between hours and SOT perspective-taking error measured in degrees. (B) Means (center

horizontal lines) and standard errors (outer horizontal lines) on the SOT for pilots holding at least a private pilot's licence versus those with no licence. Filled circles show individual scores.

Discussion

While we hypothesized that increasing hours of flight experience would be associated with better scores on all our assessments of spatial cognition, more flight hours were associated only with better small-scale perspective-taking ability and not the ability to form a cognitive map or route-based representation of a novel virtual environment. This pattern of findings was also evident when pilots' flying experience was categorized based on licensure status: those holding at least a Private Pilot Licence were more accurate on the perspective-taking task than others, but there was no difference in the virtual environment. Overall, pilots remembered specific routes more accurately than the overall map of Silcton, consistent with other research showing that only some individuals can integrate separate routes into a single mental map, both in real-world and virtual environments (Ishikawa & Montello, 2006; Weisberg et al., 2013; Weisberg & Newcombe, 2015).

The lack of an association between hours of flight experience and the Silcton direction estimation measures may be due to the difficult nature of these tasks that left little room for variation (i.e., a floor effect). In the direction estimation tasks used here, individuals must rely on memories formed during exploration of Silcton when estimating landmark directions. Error scores were closer to chance under these conditions than when participants are placed back in the virtual environment to make the estimations (e.g., see Weisberg et al., 2013). On the Silcton map-building task, hours again did not predict performance. Even though direct statistical comparisons are not possible, the pilots in our study appear to be slightly more accurate on map building ($M = .52$), compared to non-pilot samples tested with similar procedures by Weisberg et al. (2013) ($M = .48$) and Weisberg and Newcombe (2015) ($M = .47$). So, it could be speculated that pilots are marginally better than the general population on at least one Silcton task, even though performance within pilots does not vary according to hours of flight experience. Further research will be necessary to support this assertion.

The finding that more flight experience was associated with better perspective taking suggests that the skills pilots practice when flying generalize to this paper-and-pencil, non-flying task. Perspective taking involves an individual mentally transforming her heading and demonstrating accurate knowledge of the locations of objects relative to the new heading. Hegarty and Waller (2004) have asserted that perspective taking is distinct from mental rotation, another small-scale task in which the individual remains in a static orientation and imagines an object rotating around its own axis. Notably, Dror et al. (1993) found that pilots outperformed non-pilots on a mental rotation task, so it could be that both types of spatial mental transformation are improved with flight experience. We propose that perspective taking is actually the more critical ability in aviation, however, as updating the spatial position of the plane and surrounding landmarks is fundamental to maintaining navigation awareness (Aretz, 1991).

Our results suggest that better perspective taking can be acquired through increasing flight experience, although an alternative explanation is that individuals with better perspective-taking skills are more likely to progress in aviation, while those with weaker skills drop out and pursue other careers. A longitudinal design, where pilots are tested before flight training begins and then at specified intervals during training, is required to make stronger conclusions about the effect of flight on perspective taking. A similar design confirmed that structural changes in the hippocampus associated with driving a taxi were changes that occurred over the course of training rather than via attrition of those with weaker skills (Woollett & Maguire, 2011). Nonetheless, even in the absence of such longitudinal data, our findings here, coupled with our previous work (Sutton et al., 2014) point to better spatial abilities in pilots than non-pilots, and an experience-dependent effect on perspective taking.

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