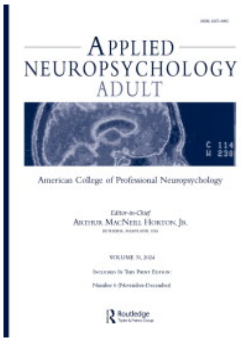

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Precision of the Integrated Cognitive Assessment for the assessment of neurocognitive performance in athletes

Daniel J. Glassbrook, Paul L. Chazot and Karen Hind

Wolfson Research Institute for Health and Wellbeing, Durham University, Durham, UK

ABSTRACT

This study investigated the precision of the Integrated Cognitive Assessment (ICA; Cognetivity Neurosciences Ltd., Vancouver, Canada) test for the assessment of information processing ability in athletes. Thirty-one participants took part in this study. Participants were eligible if they were a current contact sport or non-contact sport athlete, aged 18-40 years, and healthy; having no underlying medical issues that affect participation in sport. Participants were excluded if they were injured, pregnant, or suffering from post-concussion syndrome. Participants performed the ICA test consecutively both before and after a normal training session to simulate resting and post-sport conditions. Precision errors, relationships (Pearson's r), and internal consistency (Cronbach's Alpha) were calculated for three variables, ICA Index (overall information processing ability), ICA Speed (information processing speed) and ICA Accuracy (information processing accuracy). ICA precision errors [root mean squared-standard deviation, RMS-SD (coefficient of variation, %CV)] pre-sport were: ICA Index: 5.18 (7.14%), ICA Speed: 3.98 (4.64%), and ICA Accuracy: 3.64 (5.00%); and post-sport were ICA Index: 3.96 (4.94%), ICA Speed: 2.14 (2.32%), and ICA Accuracy 3.40 (4.25%). The ICA test demonstrates high in-vivo precision with all variables except ICA Index (7.14%) demonstrating an acceptable precision error of ≤5% %CV.

KEYWORDS

Contact sport; information processing; non-contact sport; rapid categorisation task; reaction time; reliability

Introduction

Athletes are required to demonstrate high levels of technical and perceptual decision making ability, all while under pressure and fatigue (Gabbett et al., 2008). Assessing baseline cognitive function, such as information processing and decision making ability is a valuable tool which may quantify psychological or mental ability in athletes. Indeed, good athletic performance is not only derived from physical prowess, but also an athletes ability to think and act accordingly within game situations (Harmison, 2006). Additionally, assessing cognitive function may give insight into the effect of sport participation on the brain, for example through the effect on reaction time and decision making ability. It is known that there are many positive effects of sport and exercise participation, for example: an increase in blood flow to muscles and the brain (Poels et al., 2008), and cognitive benefits such as neuroplasticity, the process of adaptive structural and functional changes to the brain in response to experience (for reviews see: Fernandes et al., 2017; Hötting & Röder, 2013; Mandolesi et al., 2018), and increases in information processing ability (Davranche & Audiffren, 2004). Exercise induced neuroplastic changes to the brain (e.g., increased brain volume, including grey matter; synaptic plasticity; and release of neurotrophic factors) can increase functional neural efficiency and cognitive functioning (Serra et al., 2011). These positive effects of exercise manifest through both biological mechanisms such as: an increase in cerebral blood flow and enhanced Oxygen delivery to cerebral tissue (Ide & Secher, 2000), and psychological mechanisms, such as: improvements in self-efficacy and self-esteem (Rodgers et al., 2014; Zamani Sani et al., 2016). Indeed, the long-term positive effect of exercise and sport participation and neuroplastic changes to brain cognition are well documented, including prevention of cognitive decline with age and a reduced risk of degenerative brain conditions (e.g., dementia) (Blondell et al., 2014; Niemann et al., 2014). Moreover, short term cognitive benefits from exercise, such as improved reaction times and visual attention have also been shown (Ando et al., 2024; Niedermeier et al., 2020), and alongside the benefits previously mentioned may also result from modulation of the central nervous system (Kashihara et al., 2009). However, physical activity can also result in a short-term reduction in cognitive ability through central and peripheral fatigue in the system, depending on the intensity and duration of the activity (Chmura et al., 1998). Accurate and reliable tests of cognitive ability administered pre- and post-exercise therefore may provide a valuable insight into the effects of exercise on cognitive performance.

CONTACT Daniel J. Glassbrook d.glassbrook@yorksj.ac.uk School of Science, Technology and Health, York St John University, York St John University Sports Park, Haxby Rd, New Earswick, York YO31 8TA, UK.

Although there are many cognitive benefits to exercise, injury is also an innate part of sport participation due to the physical nature of sport, and head impacts which may impair cognitive function are associated with participation in contact sports. One proposed method to assess the effects of possible deleterious effects of head impacts sustained during normal sport participation and cognitive function clinically is via information processing and reaction time tests. Reduced information processing ability, including memory, is linked with head impacts (Bernstein, 2002; Gronwall & Wrightson, 1981; O'Jile et al., 2006). Indeed, altered mental state and confusion are also symptoms associated with head impacts that can negatively affect memory and information processing ability (Sharma et al., 2020). Additionally, information processing speed underpins several conditions of cognitive dysfunction, for example, multiple sclerosis (Costa et al., 2017; DeLuca et al., 2004) and Alzheimer's disease (Lu et al., 2017).

Slower reaction time is a commonly used indicator of cognitive change following head impacts (Collie et al., 2003; Erlanger et al., 2001). Two common types of reaction test include measurement of simple reaction time (SRT) or choice reaction time (CRT) (Deary et al., 2011). SRT is recorded when there is only one possible stimulus (signal) and one possible response (action), for example tapping anywhere on a screen when any image appears. In CRT tasks there are two or more possible stimuli, each of which requires a quite different response, for example, tapping on the left of the screen when an image of an object appears on the screen, and tapping on the right when an image of an animal appears on the screen. SRT tests include assessments such as a weighted object drop and catch (Eckner et al., 2011), ruler drop test (Del Rossi, 2017), and somatosensory assessment, where the participant holds a device similar to a computer mouse and reacts to a vibration applied to one or both the index or middle finger, and responds by clicking with the finger (or both) that received the vibration (Tommerdahl et al., 2020). All of these types of SRT tests have been used to show slower reaction time in participants that have experienced head impacts. Computerized tests have also been shown to be sensitive and able to determine athletes who experienced head impacts versus those without, for example the CogSport choice reaction time test and Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) (Khurana & Kaye, 2012; Kira et al., 2021; Makdissi et al., 2001; Schatz et al., 2006). The CogSport choice test takes approximately 20 minutes, and consists of seven tasks including a SRT, CRT and complex reaction time task, as well as tests of visual and working memory, all designed as card games (Chen et al., 2007). The imPACT is performed with a computer screen and mouse and typically takes 20-25 minutes and comprises of six test modules assessing attention, memory, processing speed and reaction time, through tests such as word memory and symbol matching (Allen & Gfeller, 2011). Performance on these tests of reaction time is often reduced following injury and can take 10-21 days to return to baseline (Covassin et al., 2010; Del Rossi, 2017).

The Integrated Cognitive Assessment (ICA; Cognetivity Neurosciences Ltd., Vancouver, Canada) (Kalafatis et al., 2021; Khaligh-Razavi & Habibi, 2013), is a newly developed method for the assessment of information processing ability, and may be applicable to the assessment of information processing ability in athletic populations. The ICA is a short, computerized test of information processing (CRT) speed that utilizes a rapid categorization task (Kalafatis et al., 2021; Khaligh-Razavi et al., 2019). The ICA test is non-verbal and does not require color vision, and can be completed in a short amount of time (~5 minutes), on a handheld device such as an iPhone or iPad, and is therefore able to be administered easily pre- and post-sport. Additionally, the ICA has been shown to accurately detect mild cognitive impairment and be moderately to highly correlated with other popular pen-and-paper cognitive tests such as the Montreal Cognitive Assessment (Pearsons $r = 0.58$) and Addenbrooke's Cognitive Examination (Pearsons $r = 0.62$) cognitive tests (Kalafatis et al., 2021). Performing an assessment of cognitive function such as the ICA pre-sport in a rested state effectively provides a baseline measure of cognitive function. Performing a test of cognitive function post-sport then can be compared to the baseline measure of pre-sport and determine the effect of sport participation on cognitive function.

The ICA has been shown to accurately measure cognitive impairment in patients in the early stages of dementia (Kalafatis et al., 2021). However, to date, no known study has investigated the intra-day precision (i.e., how closely measurements are grouped) or intra-day reliability (i.e., consistency and accuracy of repeated measures) of the ICA test. Therefore, the purpose of this study was to determine the same-day, intra-individual precision of the ICA test to assess information processing ability. It is hypothesized that the ICA will demonstrate acceptable precision, and suitability for the assessment of cognitive function pre- and post-sport.

Methods

Thirty-one participants volunteered to take part in this study. The minimum number of participants required for precision analysis with two consecutive tests is thirty (Baim et al., 2005). Participant characteristics are presented in Table 1. Participants were recruited from March to May 2022, from the University sporting facility via advertisement flyer, and from the wider sporting community through existing relationships with sporting clubs. After initially expressing interest to take part in the study, participants were provided with an information sheet and given at least 24 hours to consider their participation in the study before a

Table 1. Participant characteristics.

	Age (Yr.)	Height (m)	Body Mass (kg)
Total (*n* = 31)	23.7 ± 5.7	1.78 ± 0.09	72.6 ± 8.3
Male (*n* = 16)	22.9 ± 4.7	1.82 ± 0.08	75.7 ± 7.4
Female (*n* = 15)	24.6 ± 6.6	1.71 ± 0.07	68.0 ± 9.9
Contact Sport (*n* = 22)	24.9 ± 6.3	1.80 ± 0.07	75.5 ± 6.0
Non-Contact Sport (*n* = 9)	20.6 ± 0.6	1.741 ± 8.3	77.2 ± 12.2

Data are presented as mean ± standard deviation. Yr., Years; m, Meters; kg, Kilograms; *n*, Number.

Table 2. Sports breakdown.

Contact Sports ($n = 22$)		Non-Contact Sports ($n = 9$)	
Rugby Union ($n = 7$)	Semi-professional, Amateur	Touch Rugby ($n = 5$)	Amateur
Boxing ($n = 6$)	Amateur	Athletics ($n = 4$)	Amateur
Muay Thai (Kickboxing) ($n = 5$)	Professional, Amateur		
Indoor Football ($n = 4$)	Amateur		

n, Number.

follow up was sent by the lead researcher. After confirmation of eligibility, participants were then booked in at a time and date of their convenience for data collection. Participants were eligible for participation if they were a current contact sport or non-contact sport athlete (Table 2) aged 18-40 years, and healthy; having no underlying medical issues that affect participation in sport. Participants were excluded if they were injured, pregnant, or suffering from post-concussion syndrome. Post-concussion syndrome is defined as the collective experience of symptoms after sustaining a concussion, such as headaches, fatigue, depression, anxiety and irritability (McInnes et al., 2017; Medicine, 1993). Details of participants racial or ethnic background was not recorded. This study was approved by the Durham University Sport and Exercise Sciences Ethics Committee (reference: SPORT-2022-01-07T10_44_59-srhd22), and written informed consent was provided by each participant prior to participation. Participant characteristics, demographics and athletic history were collected via standardized questionnaire directly after consent to participate was obtained.

To simulate resting- and post-sport conditions, participants performed the ICA test (version 1.6.0 or 1.7.0) before and after a normal training session for their respective sports. Data collection was performed in a quiet room to minimize distractions, with a maximum of two participants (separated within the room) performing the test at a time. Prior to their sports training, and within an hour of the training start time, participants completed two consecutive ICA tests. The participants then completed a normal training session and then two consecutive ICA tests again, within an hour of the training finishing.

The ICA has been described in detail in published works (Khaligh-Razavi et al., 2019; Khaligh-Razavi et al., 2020). The ICA in this study was completed on an iPad, with each test taking approximately five minutes, considerably shorter than the 20+ minute CogSport and imPACT tests; the imPACT test of which is also not portable (completed on a computer with screen and mouse). Each ICA test utilizes the brains powerful reaction to animal stimulus (Cichy et al., 2014) and comprises of 100 natural images, with 10 additional practice images provided in a practice section prior to the test. The practice images are not included in the test score. The images are a mixture of animals (e.g., birds, fish, mammals), or non-animals (e.g., objects, food, vehicles), and are presented in rapid succession. Images appear for 100 ms, followed by a 20 ms inter-stimulus interval and a 250 ms dynamic noisy mask. Participants react to the image by tapping with their thumb on the screen; on the right-hand side to select "animal" and on the left-hand side of the screen to select "non-animal." Participants were instructed to perform the test as quick as possible, and these instructions were given both verbally and presented on the screen. The test provides three variables: ICA Speed, the response reaction times in trials they responded correctly; ICA Accuracy, choice accuracy, the percentage of correct test responses; and ICA Index, overall information processing ability, a combination of ICA Speed and ICA Accuracy. Each variable is calculated by the following equations (Kalafatis et al., 2021; Khaligh-Razavi et al., 2020):

$$Accuracy = \frac{Number\,of\,correct\,categorisations}{Total\,number\,of\,images}\,x\,100$$

$$Speed = \min\left[100, 100e^{-\frac{mean\,correct\,reaction\,time}{1025} + 0.341}\right]$$

$$ICA\,Index = \left(\frac{Speed}{100}\,x\,\frac{Accuracy}{100}\right)x\,100$$

There is a speed-accuracy tradeoff in reaction test performance, and often scoring higher in either speed or accuracy is achieved at the expense of the other capacity (Liesefeld & Janczyk, 2019; Wickelgren, 1977). To combat the potential negative reflection on overall information processing ability from a poor speed or accuracy score, a common solution is the inverse efficiency score (Townsend & Ashby, 1983), whereby speed and accuracy are combined into a single score. In the case of the ICA, this concept is applied and manifests as the ICA Index variable. Test results are recorded via report immediately after test completion.

ICA Accuracy, ICA Speed and ICA Index are represented by Arbitrary Units and results of each equation are transformed and scored by a standardized scale ranging from 0 to 100. I.e., a Speed score closer to 100 indicates faster reaction times, while a Speed score closer to 0 indicates slower reaction times; an Accuracy score closer to 100 indicates higher accuracy, and an Accuracy score closer to 0 indicates lower accuracy; and an ICA Index score closer to 100 represents greater overall information processing ability, whereas an ICA Index score closer to 0 indicates poorer overall information processing ability. Additionally, the specific components included in the Speed equation (i.e., division by 1025 and addition of 0.341) further serve to standardize and scale the Speed score. These additional components are determined empirically to ensure that the Speed scores fall within the desired range of 0 to 100 for the majority of participants. Natural Log transformation further aids in normalizing the distribution of scores.

All data analysis was performed in Microsoft Excel (2016). Raw anonymized data for ICA Index, ICA Speed, and ICA Accuracy were extracted and exported to Microsoft Excel for analysis (Glassbrook et al., 2023).

Throughout the study the lead author had access to information that could identify individual participants, however, all analysis was performed on anonymized data. Precision has been previously used to define test suitability in similar cognitive tests to the ICA, such as the CogSport choice reaction time test (Straume-Naesheim et al., 2005). Precision of ICA scores and least significant change (LSC) were calculated at the 95% confidence level. Precision was determined as root mean square standard deviation (RMS-SD), coefficient of variation (CV), and percentage CV (%CV). RMS-SD represents the sample standard deviation of the differences between predicted values and observed values, and is calculated via the following formulae, where SD represents standard deviation and n represents the number of participants:

$$\sqrt{\left(\frac{\Sigma SD^2}{n}\right)}$$

The %CV expresses test variation relative to the mean of two tests and is corrected for small sample bias, and was defined as acceptable <5% (Machin et al., 2007). The LSC represents a true meaningful change was calculated from the precision errors (LSC = RMS-SD * 2.77). The two consecutive tests performed at resting and post-sport were averaged for pre- to post-test intra-day reliability evaluations. Pearson's correlation coefficient was calculated for each variable to determine reliability and the strength of the relationship between consecutive tests and between pre- to post-tests, with 0.2, 0.5, and 0.8 representing weak, moderate, and strong correlations, respectively (Cohen, 1992). Cronbach's Alpha was calculated for each variable to determine internal consistency, with 0.9, 0.8, 0.7, 0.6, 0.5 and < 0.5 representing excellent, good, acceptable, questionable, poor and unacceptable internal consistency, respectively (Cronbach, 1951).

Results

Results of the precision analysis for each ICA variable pre- and post-sport are presented in Table 3. All variables except for ICA Index pre-sport had a precision error of ≤5% %CV. LSC results are presented in Table 4. Pearson correlation coefficient and Cronbach's Alpha data for consecutive tests is presented in Table 5. All variables demonstrated strong relationships between consecutive tests pre- and post-sport, except for the ICA Index post-sport which demonstrated a moderate relationship. The ICA Index demonstrated good internal consistency for both pre-and post-sport. The ICA Speed and ICA Accuracy variables demonstrated excellent internal consistency for both pre-and post-sport. Pearson correlation coefficient and Cronbach's Alpha data for pre- to post-tests is presented in Table 6. The ICA Index demonstrated a moderate relationship between pre- to post-tests, and ICA Speed and ICA Accuracy demonstrated strong relationships between pre- to post-tests. The ICA Index and ICA Speed variables indicated good internal consistency for pre- and post-sport, and the ICA Accuracy demonstrated excellent internal consistency.

Table 3. Precision analysis results.

Variable	Precision (n = 31)		
	RMS-SD	CV	%CV
Pre			
ICA Index	5.18	0.07	7.14
ICA Speed	3.98	0.05	4.64
ICA Accuracy	3.64	0.05	5.00
Post			
ICA Index	3.96	0.05	4.94
ICA Speed	2.14	0.02	2.32
ICA Accuracy	3.40	0.04	4.25

n, Number; ICA, Integrated Cognitive Assessment; RMS-SD, Root Mean Square Standard Deviation; CV, Coefficient of Variation; %, Percentage.

Table 4. Least significant change results.

Variable	LSC (n = 31)		
	RMS-SD	CV	%CV
Pre			
ICA Index	14.36	0.20	19.78
ICA Speed	11.01	0.13	12.86
ICA Accuracy	10.09	0.14	13.9
Post			
ICA Index	10.96	0.14	13.7
ICA Speed	5.94	0.06	6.43
ICA Accuracy	9.43	0.12	11.78

LSC, Least Significant Change; n, Number; ICA, Integrated Cognitive Assessment; RMS-SD, Root Mean Square Standard Deviation; CV, Coefficient of Variation; %, Percentage.

Table 5. Relationships between consecutive tests.

Variable	Test 1	Test 2	Correlation (r)	Cronbach's Alpha (α)
Pre				
ICA Index	76.6 ± 8.3	82.2 ± 6.1	0.82	0.88
ICA Speed	88.6 ± 8.1	92.3 ± 7.3	0.85	0.91
ICA Accuracy	86.9 ± 8.9	89.2 ± 6.2	0.87	0.90
Post				
ICA Index	81.5 ± 7.0	83.0 ± 6.7	0.68	0.81
ICA Speed	94.8 ± 5.2	95.6 ± 4.6	0.82	0.90
ICA Accuracy	86.1 ± 9.1	87.0 ± 8.3	0.85	0.92

ICA, Integrated Cognitive Assessment; Data are presented as mean ± standard deviation.

Table 6. Relationships between pre- and post-sport tests.

Variable	Pre-Sport	Post-Sport	Correlation (r)	Cronbach's Alpha (α)
ICA Index	79.4 ± 6.9	82.3 ± 6.3	0.69	0.81
ICA Speed	90.4 ± 7.4	95.2 ± 4.7	0.85	0.87
ICA Accuracy	88.1 ± 7.3	86.5 ± 8.3	0.85	0.92

n, Number; ICA, Integrated Cognitive Assessment; Data are presented as mean ± standard deviation.

Discussion

The purpose of this study was to determine the same-day, intra-individual precision and reliability of the ICA test to assess information processing ability. The results of this study support the ICA as a tool with acceptable precision to measure changes in information processing ability pre- and post-sport, confirming the hypothesis. All ICA variables in this study, except for ICA Index pre-sport demonstrated a precision error of ≤5% %CV. All variables demonstrated moderate to strong relationships and good to excellent internal consistency between consecutive tests pre- and post-sport, and between pre- to post-tests. The ICA may be clinically relevant for the assessment of information processing ability, and the effect of sport on information processing ability.

The higher ICA Index precision score (7.14%CV) pre-sport than post-sport (4.94%CV) in this study may be explained by the larger average difference between test one and test two pre-sport (76.6 ± 8.3 to 82.2 ± 6.1), compared to a smaller average difference in ICA Index scores between test one and test two post-sport (81.5 ± 7.0 to 83.0 ± 6.7). This is further exemplified by a larger ICA Index RMS-SD pre-sport than post-sport (5.18 and 3.96, respectively), which indicates more variance in observed data around the mean. This result may be due to an increased level of comfort with the test from the first pre-sport ICA test to the subsequent test, and possibly a learning effect. However, this is in contrast to previous work which showed no learning effect for the ICA test in healthy participants and those diagnosed with dementia (Kalafatis et al., 2021). Additionally, a strong relationship ($r = 0.82$) and good internal consistency ($\alpha = 0.88$) between ICA tests and the ICA Index variable was observed pre-sport (Test 1 and Test 2; Table 5), further suggesting a minimal learning effect, and supporting the test as reliable.

All variables showed greater precision post-sport compared to pre-sport. Therefore, the ICA appears to be sensitive enough to measure improvements in information processing ability related to engagement in physical activity. These results may be due to the many positive physiological benefits that exercise has, such as an increase in blood flow to muscles and brain (Poels et al., 2008), structural and functional changes in the brain (Fernandes et al., 2017), and increases information processing ability (Davranche & Audiffren, 2004). Indeed, improvements in information processing ability after a bout of exercise is supported by previous research (Lemmink & Visscher, 2005; Niedermeier et al., 2020). Caution should be exercised if employing the ICA as a method to measure potential concussion in sport, however. Performance improvements in ICA variables pre- to post-physical activity as a result of positive physiological benefits may mask negative changes in information processing ability related to concussion, or changes in performance could be misattributed to head injury when none has occurred.

Previous research looking at precision in a similar cognitive test to the ICA, the CogSport choice reaction time test, has shown lower %CV for mean choice reaction time (speed) (1.4%CV), and higher %CV for choice reaction time accuracy (11.4%CV) (Straume-Naesheim et al., 2005). These results are interesting as the ICA is shown to be less precise in measuring reaction speed (2.32 – 4.64%CV vs 1.4%CV), however, the ICA test is shown to be more precise in terms of accuracy (4.25–5.00%CV vs 11.4%CV). These results may indicate that the test you adopt needs to be specific to the variable of interest (i.e., speed or accuracy), however, this should be negated in the case of the ICA via the ICA Index variable as an inverse efficiency score (Townsend & Ashby, 1983), whereby speed and accuracy are combined into a single score. The contrasting results between the present study and that of Straume-Naesheim et al. (2005) may be due to the populations used; the CogSport test was used in elite football players only, whereas only a small percentage of the participants in the present study are practicing professionally (Table 2). The present study recruited participants from a variety of sports, each with their own decision making and reaction characteristics, in comparison to only football. Additionally, a greater number of participants ($n = 289$) performed the CogSport test in comparison to the ICA in the present study ($n = 31$). However, the administration procedure of the CogSport test was similar to the administration of the ICA test, and was also administered under controlled conditions, i.e., in a quiet room to minimize distractions and with more than one participant performing the test at a time.

A limitation to this study is that information about the specific duration and intensity of training sessions undergone by participants was not recorded. Only that it was a typical or normal training session. i.e., not a session of just running or conditioning, and included practice of the sport itself. Additionally, the optimal intensity and duration of exercise that may impact information processing ability was not assessed. A relatively small sample size was used, although the sample size exceeds the minimum of 30 participants required for precision analysis with two consecutive tests (Baim et al., 2005), a greater number of participants could strengthen the statistical analysis. Future studies should look to recruit larger numbers, and complete comparisons between contact and non-contact sports, and between amateur and professional level participants.

In conclusion, the ICA is a practical test which can be used to measure information processing ability before and after sport participation. The results of this study support the ICA as a precise (as determined by %CV values) measure of information processing speed and information processing accuracy, and overall information processing ability (ICA Index). The ICA can be used for the assessment of information processing ability, and may be useful as a method to assess the effects of sport on information processing ability.

Disclosures statement

No potential conflict of interest was reported by the author(s).

Data availability and materials statement

The datasets generated during and/or analyzed during the current study are available in the figshare repository: https://figshare.com/articles/dataset/ICA_Precision_Raw_Data_xlsx/22211644.

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ORCID

Daniel J. Glassbrook http://orcid.org/0000-0002-3317-8791
Paul L. Chazot http://orcid.org/0000-0002-5453-0379
Karen Hind http://orcid.org/0000-0002-4546-5536

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