Unknitting the Meshwork: Interactivity, Serendipity and Individual Differences in a Word Production Task

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Abstract

Creative ideas emerge from a meshwork of dynamic elements. Resources internal and external to the agent configure a cognitive ecosystem that scaffolds performance. In addition, capitalizing on fortuitous external cues may trigger new ideas. We examined these elements to determine how they come into play during a simple word production task. Participants were video recorded as they generated new words from 7 letter tiles in three different environments (i) high interactivity where the titles could be moved at will (ii) low interactivity where they could not, and (iii) low interactivity where the order of the tiles could be shuffled but once shuffled no additional actions were allowed. Overall, interactivity had a marginally positive impact on performance, while independent measures of participants' verbal fluency were strong predictors of performance in all environments. Based on a detailed coding of the video data, a finer-grained analysis of behaviour in the high interactivity condition revealed that the time participants spent manipulating the tiles was a significant predictor of performance. The video data also allowed us to measure the average latency to the production of a new word after shuffling the letters in the low interactivity condition as an index of how 'lucky' the reset was: Shorter average latencies were a significant predictor of overall word production. These data indicate that interactivity, serendipity, and internal cognitive resources determine problem-solving performance in this task.

Keywords: Creativity; interactivity; serendipity; cognitive eco system.

Introduction

Problem solving is an activity that takes shape in a dynamic meshwork of resources and processes, configured from internal mental resources, embodied actions and environmental affordances. To better appreciate the role of interactivity in problem solving it is important to contrast problem solving performance in task ecologies that differ in the degree to which a problem solver can 'think' through the manipulation of a physical model of the problem. In a low interactivity task environment, the problem solver is decoupled from her immediate environment: She is invited to solve a problem without using her hands to support thinking either through gesture or rearranging the physical elements that configure a model of the problem (such task environments are often the default procedure employed in problem solving research, Vallée-Tourangeau & March, 2019). In other words, problem solving proceeds from mental simulations of possible solutions. In contrast, a high interactivity task environment places no such constraints on her: Participants are presented with physical elements of the problem that can be manipulated to arrive at a solution. In such environments, proto solutions are boundary objects of sorts (Fiore & Wiltshire, 2016) that are physically constructed and perceived, unveiling action affordances and guiding attention in ways that are simply not possible in low interactivity conditions. Creative problem solving in a task ecology that favours interacting with the physical elements of a problem, is driven by three factors: the internal resources of the problem solver, her embodied behaviour and the environmental affordances that unfold dynamically as the physical model of the problem is modified. A full account of these aspects helps better appreciate their transactional nature.

Interactivity in the Word Production Task

The game of Scrabble has been modified to assess whether manipulating the letter array supports word production (see Maglio, Matlock, Raphaely, Chernicky & Kirsh, 1999; Webb & Vallée-Tourangeau, 2009; Vallée-Tourangeau & Wrightman, 2010; Kirsh, 2014; Fleming & Maglio, 2015). In this modified task participants are given 7 letters and invited to generate words. With an open problem of this sort, the dependent measure offers a more nuanced measure of the benefit or otherwise of interactivity. Additionally, letter set difficulty can be manipulated by selecting sets of letters that generate more or fewer words.

There are clear theoretical reasons to suppose that interactivity would benefit solvers in a word production task of this kind. By extending the mental workspace outside of the head, the internal letter representations are reified and are easily manipulated freeing up and scaffolding participants' internal resources (Gavurin, 1967; Webb & Vallée-Tourangeau, 2009; Vallée-Tourangeau & Wrightman, 2010). Furthermore, interactivity allows the solvers to move with less effort through the problem space and even to jump to new places with, at times, unplanned moves (Maglio et al., 1999). Thus, the tiles may either be recruited strategically or, more serendipitously, non-strategic moves may yield lucky combinations of letters.

Empirically, however, the data are less clear than may be imagined. The only study that demonstrates an unequivocal benefit is Flemming and Maglio (2015) where interactivity not only led to an increase in word production but also to rarer (less frequent) words being produced. While Maglio et al. (1999) documented a small overall benefit for interactivity, when this was broken down into the two different letter sets used, interactivity led participants to produce more words with one letter set but fewer words with another, easier, letter set. With an easy letter set, participants are more capable of generating words without help so the added cost of manipulating tiles may actually slow down word generation. In addition, the serendipitous jumps proposed by Maglio et al. (1999) are less likely to occur when a participant can easily produce words.

Individual Differences

Where the participants have been profiled, the existing data show a clear interaction between the individual resources of the problem solver and the effect of interactivity. Vallée-Tourangeau and Wrightman (2010) found that there was a statistically significant benefit in the high interactivity condition for participants categorised in the low verbal fluency group while the benefit for those in the high verbal fluency group was negligible. This mixed story is echoed by Webb and Vallée-Tourangeau (2009) who manipulated the difficulty of level sets across two groups, children with and without developmental dyslexia. Here the number of words produced by each group depended on the difficulty of the letter set: Interactivity only benefitted the control group with the harder letter set and the children with developmental dyslexia only benefitted from interactivity with the easy set. The evidence to date suggests that interactivity scaffolds the performance of those who have lower verbal fluency or working memory and acts as an additional, reciprocal and non-linear processing loop (Vallée-Tourangeau & Vallée-Tourangeau, 2017) but it appears to confer little benefit when the task is within the capability of the participants either because of their skills or the nature of the letter set employed.

Environmental Affordances

For Maglio et al. (1999) the benefit of high interactivity was in no small part due to the introduction of randomness that seeds intelligent behaviour. Randomness is generated by the external environment and interactivity research explores the way problem solvers both recruit and are entangled with this environment (Ingold, 2017). Kirsh (2014) explicitly examined this role of randomness in the word production task. The participants were invited to take part in a task on a computer with an additional shuffle condition where one click shuffled the letters randomly. He found that the shuffle condition encouraged the production of a significantly higher number of words (M = 18.9) than both the static (M = 16.6) and the interactive (M = 17.7) conditions.

If we consider the constraints in place across Kirsh's three conditions, this becomes a more surprising result. As there were no reported constraints in the high interactivity condition, it theoretically provides the widest range of possible strategies. Participants are not prevented from shuffling the tiles randomly, just such shuffling would have to be self-generated. In practice, it seems unlikely that participants could have fully used the range of possibilities of the high interactivity version. Indeed, the number of shuffles described by Kirsh—the best performing third shuffled once every 3.7 seconds, the worst performing third once every 1.9 seconds—demonstrate the incredibly low cost of shuffling to generate hints in this task environment. In practice, it would be impossible to mimic this strategy with the high interactivity version in the same time.

Just as the skills of the problem solver are important when we consider the ways cognition arises from the interplay between person and external artefacts, so too are the affordances for action offered by the artefacts. Taking the cognitive ecology of this task seriously, requires taking the affordances of the external environment seriously. Rather than making the implicit assumption that the problem solver imposes her will on an inert and indifferent environment, we suggest that the nature of the artefacts selected will determine to some extent the actions undertaken (Steffensen, Vallée-Tourangeau & Vallée-Tourangeau, 2017).

It is our hypothesis that in Kirsh (2014) the low cost of shuffling the tiles with one click on a computer compared to the relatively high cost of moving tiles with a mouse, meant that shuffling functioned as an epistemic action (Kirsh & Maglio, 1994) more closely resembling the actions of a Tetris player who chooses a tretromino drop location based on what she sees *after* multiple physical rotations rather than a true test of luck. Indeed, Kirsh (2014, p. 19) acknowledges this: "the cost in time and mental effort must be sufficiently low that it pays to keep fishing for hints". The benefits of interactivity are only useful when they outweigh the costs of that interactivity (Maglio et al, 1999) and the shuffle condition reported in Kirsh (2014) is incredibly low in cognitive cost. Thus, while environmental randomness was examined it remains to be seen to what extent its benefit resulted from the low cost involved in monitoring the usefulness of a change in the letter array rather than having to take the time or make the mental effort to produce different arrays.

Participant Behaviour

The manipulation of chance by Kirsh (2014) also highlights differences in participants' behaviour. The number of shuffles varied across shufflers. Indeed, the better word generators shuffled "about 50% less" (p.18) than those who produced the fewest words. So, while the shuffle condition produced a higher overall mean of words, when the behaviour of the participants is taken into account, a more nuanced and accurate account of the role of chance is possible. Shuffling did not confer an indiscriminate benefit across all participants.

This difference in the behaviour of the participants is also acknowledged in a footnote in Maglio et al. (1999, footnote 2, p. 330): roughly a third of the participants did not consider it worth using their hands to structure their thoughts in an ostensibly high interactivity environment. This footnote requires us to consider to what extent the participants in this experimental condition could be said to be using interactivity; rather the condition might be more aptly renamed *potential* for high interactivity.

In various experiments investigating the role of interactivity in problem solving (e.g., Vallée-Tourangeau, Sirota & Vallée-Tourangeau, 2016), the low interactivity condition is invariably tightly controlled, and participants' movements are constrained with them often being requested to lay their hands flat on the work surface. However, there are few controls and rarely any consideration of the manner in which participants recruit resources in a task environment labelled as high interactivity. Only Fleming and Maglio (2015) have taken a closer look at the behaviour of participants in a high interactivity condition. In contrast to Maglio et al. (1999), they suggest that all their participants moved the tiles. However, as the focus of their paper was strategy selection rather than the time spent interacting, the detailed analysis required restricted their coding to the behaviour of 8 participants in the final block with a specific aim of looking for and coding word production strategies. If we are to profile the whole system (Vallée-Tourangeau & Vallée-Tourangeau, 2017) then the level of interaction becomes important each time the participants encounter the tiles as a measure in itself rather than solely as an indication of strategy, especially if the different levels of interactivity designed in these environments do not result in differences in participants' behaviour.

It is further unclear how much participants' behaviour differs as a function of their individual differences. It is plausible that those who do not need the help of the tiles recruit them less. Research on expert Tetris players suggests an inverted U shape relationship of action and expertise with complementary actions decreasing as expertise increases (Destefano, Lindstedt & Gray, 2011). It is not unreasonable to expect a similar relationship in this task.

The Current Experiment

We examined the role of interactivity and chance in a word production task as well as the moderating properties of participants' verbal fluency. Rather than a computer and mouse we employed physical letter tiles. These artefacts more naturally invite interaction in the high interactivity condition and conversely increase the cost of movement in the shuffle condition testing if the benefits of shuffling hold when the nature of the artefacts are taken into consideration. We video recorded participants to undertake a more granular analysis of their behaviour in the high interactivity condition. This allowed us to assess the number of participants in the high interactivity condition who actually chose to move the letter tiles and determine the amount of time they actually interacted with the tiles. In this way, we can begin to disentangle some of the complexities that underlie the reported aggregated means in the high interactivity and the shuffle conditions.

We hypothesised that the increased time and cognitive cost of shuffling would lead to a reduction in the average number of shuffles and so, contrary to Kirsh's findings, we further hypothesised that the high interactivity condition would yield the most words followed by the shuffle condition reflecting the relative cognitive and time costs of each condition. Further, that video data would reveal a range of engagement with the tiles and capture the participants who do not avail themselves of the affordances for creativity in a high interactivity task environment. In line with the data reported for shuffling in Kirsh (2014), we expected an optimum level of interactivity beyond which there would be no further benefit. We hypothesised that verbal fluency would significantly moderate not only the total word count but participant behaviour, that is that high verbal fluency participants might not interact with the letter tiles to the same degree as low verbal fluency participants.

Method

Participants

Forty-two participants took part in the experiment in exchange for course credits. Two participants did not consent to be filmed and still received credit but as their behaviour could not be coded, their data were excluded. This left data for 40 participants (32 females, M_{age} = 25.65, *SD* = 7.17).

Design

The experiment used a repeated measures design with the order of the three experimental conditions counterbalanced across participants. The three conditions were high interactivity, low interactivity, and low interactivity + shuffle.

Materials and Measures

Three sets of 7 letters (COTFAED, NDRBEOE and TVAERWI) were created with similar average number of possible words of similar frequencies[1] piloted in a prior norming task. In each condition, the participants were given 5 minutes to call out as many words as they could from a set of 7 letter tiles (2cm * 2cm) initially presented in a straight line with the following constraints (i) the words must be at least three letters long and (ii) proper names and acronyms were not allowed. In the high interactivity condition, participants were invited to move the tiles as they saw fit. In the low interactivity condition, they were asked to not move or interact with the tiles in any way. Finally, in the shuffle condition, they were invited "whenever you want to and as many times as you want to" to collect all the tiles up, shake them in closed hands and lay the tiles out again in the new, randomly generated order. In the shuffle condition, when not shuffling the tiles, participants' movements were constrained in the same way as in the low interactivity condition. The dependent variable was the number of words generated by the participants in the three task environments.

Participants were also profiled along three further measures. First, performance on a modified version of the Thurstone (1938) test, which involves writing as many words with the letter S in five minutes and then as many words with the letter C in four minutes, was used to index participants'

[1] Frequencies taken from Zipf scores presented in the SUBTLEX-UK database (Van Heuven, Mandera & Keuleers (2014).

verbal fluency. Second, participants were invited to complete 12 5-letter anagrams taken from a larger set in Webb, Little and Cropper (2016) to assess their skills at anagramming. Finally, their levels of openness to experience was measured using the relevant items from the scale used in Lee and Ashton (2004); although there is little firm evidence on the role of personality traits and luck, this trait has been previously linked to a propensity to experience luck (McCay-Peet, Toms & Kelloway, 2015) and was added as an exploratory measure to assess if participants high on this trait would leverage the luck or otherwise of the shuffle condition.

Procedure

The anagram and verbal fluency tests were used as warm up tasks before the three main experimental conditions. The measure of extraversion was placed at the end of the study producing the following order:

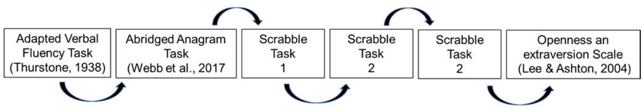

Figure 1: The order of the tasks.

The order of the conditions was counterbalanced across participants as was the set of letter tiles associated with each condition.

Qualitative Coding

In the high interactivity condition, the amount of time participants spent moving the tiles was coded using ELAN. The total time interacting with the tiles was assessed from when a participant touched a tile to when he or she stopped touching it. As there were many moments when a participant touched a tile but did not move it, this was further split into neutral moves (which did nothing to alter the array) and active moves (which changed the array in some way, either deliberate or random). Active moves were considered a reflection of interactivity. In the shuffle condition the number and timing of the shuffles was also recorded in ELAN. The timing of the shuffle was calculated from the moment participants touched the tiles until they had re-laid the array. In some instances, participants generated a word while relaying the tiles after the shuffle and therefore before the end of the full shuffle process; in these cases, the shuffle-new word latencies were negative.

Results

There was broadly similar performance in each experimental condition. Participants produced the highest number of words in the high interactivity condition (M = 18.4, SD = 8.5). There was virtually no difference between the performance in the low interactivity (M = 17.0, SD = 6.2) and shuffle (M = 17.2, SD = 6.2). While there was a slight benefit of interactivity, a one-way repeated measures analysis of variance revealed this to be non-significant, $F(2, 78) = 1.97$, $p = .146$, $\eta p^2 = .048$.

Correlations among measures of verbal fluency, anagram performance, openness and word production in the three experimental conditions are reported in Table 1 (df = 38). As expected, verbal fluency significantly correlated with performance in the high condition, $r = .717$, $p < .001$, the low condition, $r = .734$, $p < .001$ and the shuffle condition, $r = .745$, $p < .001$. Anagram skill also correlated highly with performance in the high, $r = .601$, $p < .001$, low, $r = .679$, $p < .001$ and shuffle conditions, $r = .630$, $p < .001$. There were no significant correlations between the measure of openness to experience and performance in any of the conditions.

Performance in the High Interactivity Condition

The video data enabled us to examine and analyse in finer detail the behaviour of the participants in the high interactivity condition. As we reviewed in the introduction, not all participants avail themselves of the opportunity to interact with the external environment. It is insufficient to analyse group level performance to determine the benefits of interactivity in the absence of a more detailed analysis of individual behaviour and performance. As expected, the video data revealed large differences in the behaviour of the participants in the high interactivity task environment. Active moves constituted 86% of the total time spent touching the tiles. Two participants opted not to interact with the tiles at all. The range of the time spent actually interacting with the letter tiles was 2.9 seconds to 226.9 seconds with a mean time of 106.4 seconds (SD = 65.10). The relationship between time interacting and the number of words produced is displayed in Figure 2. As the scatterplot reveals, the longer the participants interacted with the tiles the more words they produced. This relationship was significant, $r(38) = .329$, $p = .038$ and indeed becomes stronger when the effects of anagram skills and verbal fluency are partialled out, $r(38) = .439$, $p = .006$ offering a more direct measure of the impact of interactivity on word production. Contrary to our prediction and the observed shuffling behaviour in Kirsh (2014), interactivity conferred a steady benefit with no tailing off.

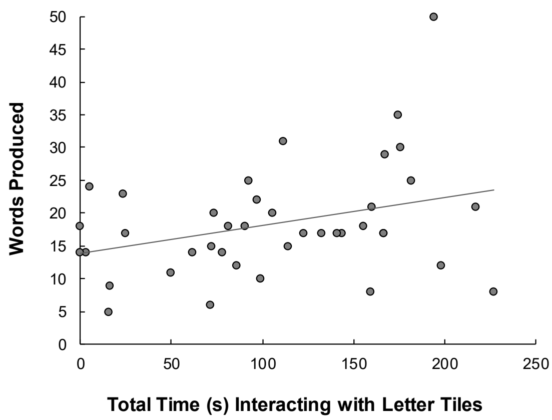

Figure 2: Number of words produced in the high interactivity condition as a function of the time (in seconds) spent interacting with the letter tiles.

Table 1: Descriptive statistics for and correlations among measures of verbal fluency, anagram performance, openness, and word production performance in the three experimental conditions.

	M	*SD*	1	2	3	4	5	6
1. Fluency score	88.30	25.15	-					
2. Anagram total	8.90	2.73	.493 **	-				
3. Openness	102.75	15.25	-.018	-.046	-			
4. High word count	18.35	8.49	.717 **	.601 **	-.230	-		
5. Low word count	17.03	6.59	.734 **	.679 **	-.173	.819 **	-	
6. Shuffle word count	17.23	6.23	.745 **	.630 **	-.019	.848 **	.796 **	-

** $p < .001$ level (2-tailed).

Finally, in contrast to our prediction, the extent to which a participant recruited the letters to aid thinking did not significantly correlate with either verbal fluency, $r(38) = .111$, $p = .481$, or anagram skills, $r(38) = -.032$, $p = .844$.

Performance in the Shuffle Condition

Participants shuffled an average of 1.58 times; there was, however, a wide variation in the number of shuffles. Twenty five percent of the participants opted not to shuffle at all, 17.5% of participants opted to shuffle once, 30% twice and a further 27.5% opted to shuffle 3 times.

As predicted, there was a large time cost to shuffling. The average shuffle took 17.51 seconds ($SD = 3.51$) with the fastest shuffle being 10.22 seconds and the slowest taking 24.64 seconds. Overall, shuffling appeared to be an unhelpful strategy. Participants' word production performance did not differ among those who did not shuffle ($M = 17.81$, $SD = 6.58$), shuffled once ($M = 17.12$, $SD = 5.02$), twice ($M = 16.58$, $SD = 7.35$) or three times ($M = 16.81$, $SD = 6.30$), $F < 1$.

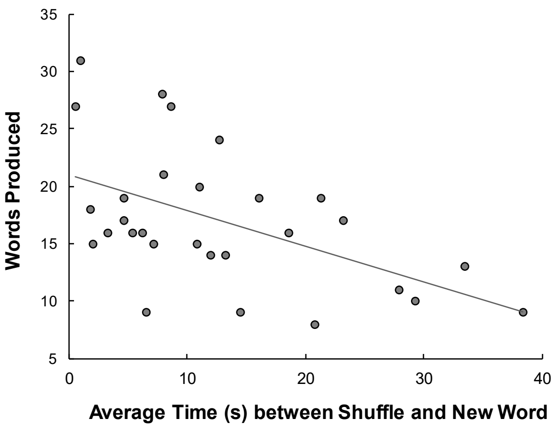

Figure 3: Number of words produced in the shuffle condition as a function of the average time (in seconds) before a word is produced after shuffling the letter tiles.

The effect of the shuffles also varied widely. The average time after the end of shuffling to generate a word was 11.69 seconds ($SD = 13.77$). The minimum time after shuffling to produce a word was -5.05 seconds (producing a word while relaying the tiles after the shuffle) whereas the maximum time after the shuffling had ended to producing another word was over a minute (61.72 seconds). Only one participant did not produce any words after her first shuffle and went on to shuffle again.

It seems likely that a word produced directly after a shuffle has been stimulated by that shuffle whether that shuffle directly yielded the word or whether the act of shuffling and laying out of the tiles stimulates further thought. We thus measured how long after a shuffle a word was produced as a proxy measure of the luckiness of the shuffle – the faster a word was produced the luckier the shuffle. The relationship between this time (averaged out for those participants who had more than one shuffle) and the total number of words produced overall in the shuffle condition is illustrated in Figure 3. The correlation was significant, $r(27) = -.520$, p = .004 even when controlling for verbal fluency and anagram skill, $r(27) = .422$, p = .028, suggesting that the nature of the array produced by the shuffle and the words it stimulated was important to the overall number of words produced in that condition.

Discussion

This experiment was designed to trace the influence of interactivity, serendipity and verbal fluency in a word production task. These three elements create a dynamic meshwork from which word production skills are enacted. The differences in the mean number of words produced in the three experimental conditions were marginal albeit showing a general trend in line with past findings favouring high interactivity. When performance is viewed through the lens of a condition's mean score with individual variation in behaviour and cognitive skills flattened, the benefits of interactivity in this task are not clearly revealed. While there has been some examination of cognitive profiles which benefit from interactivity, the implicit assumption in previous research has been that there has been no difference in participant behaviour in the high interactivity condition.

However, by subjecting participant behaviour to a finer granularity of analysis, we can start to disentangle how that behaviour affects the numbers of words produced and isolate a purer effect of interactivity. Given that two participants did not interact with the letter tiles at all, it is illogical to attribute their scores in both the low and high interactivity conditions to different factors (in effect, despite our best efforts to change the task ecology, these participants approached the high and low interactivity conditions in the same manner). Again, those participants who chose not to shuffle essentially participated in an additional low interactivity experimental condition. It is meaningless to assign one score to low and one to shuffle unless we are measuring the effect of experimental instructions.

When the behaviour of the participants is taken into account, there was a significant correlation between the time spent interacting with the letter tiles and the number of words produced in that condition even when controlling for verbal fluency skills. This suggests that interactivity boosts word production only when a participant fully engages in that condition. Measuring participants' behaviour is important and designing a high interactivity task environment does not guarantee that the affordances inherent to a dynamic problem-solving environment will be perceived and exploited to boost performance. Contrary to expectation, there was no relationship between verbal fluency and the time spent interacting. This is in contrast to prior observations on the different effect of interactivity on different individual difference profiles: interacting with the tiles helped everyone.

Further, there was failure to replicate Kirsh's (2014) observation that engineered randomness boosts performance. However, the nature of the current experiment increased the impact of an unlucky shuffle by increasing the time and cognitive cost of shuffling as the materials were moved from a digital to a material environment. This led to a predicted decrease in the number of participants who opted to shuffle and the number of times they shuffled along with a much higher investment in the array produced by the shuffle than that reported by Kirsh. The inherent contingent and transactional nature of luck in this task was partly captured by the latency to first word produced after a random re-arrangement. These average latencies were significant predictors of how many total words would be produced in this otherwise low interactivity environment. It would be interesting to couple the luck and high interactivity manipulation in future research.

The current results suggest that previous research into interactivity may have underestimated its benefit by failing to subject behaviour to a sufficiently granular analysis which can only be done with detailed video coding of behaviour (see also Steffensen, Vallée-Tourangeau, & Vallée-Tourangeau, 2016). A problem solver's trajectory is unique and the interaction with a richer set of environmental resources will trigger more complex behaviours. Thus, it behoves us to take a closer look at what is actually happening in a task environment that fosters interactivity. Interactivity is contingent and messy: its study must take into account the behaviour of the participant and the nature of the materials being used to more accurately capture the factors that drive creative problem solving.

References

ELAN (Version 5.2) [Computer software]. (2018, April 04). Nijmegen: Max Planck Institute for Psycholinguistics. Retrieved from https://tla.mpi.nl/tools/tla-tools/elan/

Destefano, M., Lindstedt, J. K., & Gray, W. D. (2011). Use of complementary actions decreases with expertise. In L. Carlson, C. Hölscher, & T. Shipley (Eds.), *Proceedings of the 33rd Annual Conference of the Cognitive Science Society* (pp. 2709–2014). Austin, TX: Cognitive Science Society.

Fleming, M., & Maglio, P. P. (2015). How physical interaction helps performance in a Scrabble-like task. In D. C. Noelle, R. Dale, A. S. Warlaumont, J. Yoshimi, T. Matlock, C. D. Jennings, & P. P. Maglio (Eds.) *Proceedings of the 37th Annual Conference of the Cognitive Science Society* (pp. 716-721). Austin, TX: Cognitive Science Society.

Gavurin, E.I. (1967) Anagram solving and spatial aptitude. *The Journal of Psychology*, *65*, 65-68.

Fiore, S. M., & Wiltshire, T. J. (2016) Technology as teammate: Examining the role of external cognition in support of team cognitive processes. *Frontiers in Psychology, 7*, 1531.

Ingold, T. (2017). On human correspondence. *Journal of the Royal Anthropological Institute*, *23*, 9-27

Kirsh, D. (2014). The importance of chance and interactivity in creativity. *Pragmatics & Cognition*, *22*, 5-26

Lee, K., & Ashton, M. C. (2016). Psychometric properties of the HEXACO-100. *Assessmen*t, *25*, 543-556

Maglio, P. P., Matlock, T., Raphaely, D., Chernicky, B., & Kirsh, D. (1999). Interactive skills in Scrabble. In M. Hahn, & S. C. Stoness (Eds.), *Proceedings of the 21st Conference of the Cognitive Science Society* (pp. 326-330). Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

McCay-Peet, L. Toms, E.G. & Kelloway, E.K. (2015). Examination of relationships among serendipity, the environment, and individual differences. *Information Processing and Management*, *51*, 391-412.

Steffensen, S. V., & Vallée-Tourangeau, F. (2018). An ecological perspective on insight problem solving. In F. Vallée-Tourangeau (Ed.), *Insight: On the origins of new ideas* (pp. 169-190). London: Routledge.

Steffensen, S. V., Vallée-Tourangeau, F., & Vallée-Tourangeau, G. (2016). Cognitive events in a problem-solving task: Qualitative methods for investigating interactivity in the 17 animals problem. *Journal of Cognitive Psychology*, *28*, 79-105.

Thurstone, L.L. (1938). *Primary mental abilities*. Chicago: University of Chicago Press.

Vallée-Tourangeau, F., & March, P. L. (2019). Insight out: Making creativity visible. *Journal of Creative Behavior.*

Vallée-Tourangeau, F., Sirota, M., & Vallée-Tourangeau, G. (2016). Interactivity mitigates the impact of working memory depletion on mental arithmetic performance. *Cognitive Research: Principles and Implications*, *1*, 26.

Vallée-Tourangeau, G. & Vallée-Tourangeau, F. (2017). Cognition beyond the classical information processing model: cognitive interactivity and the systemic thinking model (SysTM). In Cowley, S. J., & Vallée-Tourangeau, F. (Eds). *Cognition Beyond the Brain*. London: Springer.

Vallée-Tourangeau, F., & Wrightman, M. (2010). Interactive skills and individual differences in a word production task. *AI & Society*, *25*, 433-439.

Webb, M. E., Little, D. R., & Cropper, S. J. (2018). Once more with feeling: Normative data for the aha experience in insight and noninsight problems. *Behavior research methods*, *50*, 2035-2056.

Webb, S., & Vallée-Tourangeau (2009). Interactive word production in dyslexic children. In N. Taatgen, H. van Rijn, J. Nerbonne & L. Schomaker (Eds.), *Proceedings of the 31st Annual Conference of the Cognitive Science Society*. (pp. 1436–1441). Austin, TX: Cognitive Science Society

Van Heuven, W., Mandera, P., Keuleers, E., Brysbaert, M. (2014). Subtlex-UK: A new and improved word frequency database for British English. *Quarterly Journal of Experimental Psychology*, *67*, 1176-1190.