Conditions for Maximizing Effects of 90 Days of Brain Training

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Abstract

In this paper, we analyze variations of cognitive profiles, training patterns and results of 350 members of an international online brain training website over a 90-day fixed period of training. Our goal is to identify conditions necessary for maximizing effectiveness of an adaptive brain training program on adults. Data show a significant improvement of cognitive profile, which is correlated to the intensity of training but not correlated to gender, level of education, language or age. The number of exercises is a critical part of a brain training program to ensure a transversal improvement and not an exercise-dependent improvement directly linked to task learning. Data analysis suggests a training recommendation of 30-40 minutes per day 5 days a week for maximizing effects of 90 days of brain training.

Context

Many recent research studies have shown that targeted brain training can help improve cognitive functions. For instance, a meta-analysis of published studies in peer-reviewed journals Papp, Walsh & Snyder (2009) showed that short-term memory improvements can be obtained when using a computerized brain training program. These improvements last longer than the training itself (Willis et al., 2006). Similarly, cognitive training can help adults improve some cognitive skills in the early stages of cognitive impairment and dementia (Sitzer et al, 2006).

Since 2000, we are working on building an adaptive brain training program supported by an interactive and personalized coaching process. Training sessions are built according to past results and behaviors. Adapted activities and difficulty levels are proposed to users. Users also have the opportunity to control game play but recommendations are always provided.

In this context, the question becomes what are the conditions of effectiveness of an adaptive brain training program on adults? In particular, we look for answers to the following questions:

- How much should someone train to have significant improvement on his/her cognitive profile?
- Is computerized brain training more effective on certain populations of individuals (age, gender, education, native language)?
- Is there an ideal regimen or approach of brain training that produces the optimal results?

Method:

We analyze variations of cognitive profiles (see definition further) and training patterns of HAPPYneuron's online members over a 90-day fixed period of training.

The website www.happyneuron.com offers 40 training exercises that target 5 major cognitive functions: Memory, Attention, Language, Executive Function and Visual-Spatial skills. It is available in

11 languages but we limit our study to English, French and German communities. Here are the key information important to know about the program:

- The training program is provided to users who subscribe (about $10 per month).
- The brain training program targets independent, healthy people.
- The exercises were designed by a team of neurologists, neuropsychologists and cognitive psychologists, headed by Dr. Bernard Croisile, MD Neurology, PhD. Neuroscience.
- Each game includes multiple game plays and difficulty levels (usually between 10 and 50).
- Game interfaces and usability are validated by 2 research groups (20 seniors) from the "Université Tous Ages" ("University for Elderly People", Lyon 2 University, France).
- Each game measures accuracy and speed. Then, a global score is normalized on a 0-100 scale comparing performance to the results of peers (same gender, level of education, and age class) at the same difficulty level using a percentile-based technique which relies on standards computed from collected results of the website's visitors (about 100 Million on January 2012 for all games/all languages). If a user scores 50 the result indicates that 50% of their peers have scored better and 50% have done worse. If the raw result deviates too far from what is considered a "normal" performance, it is ignored (e.g. poor accuracy but very high speed suggesting a non-serious attempt).
- Each member has a cognitive profile composed of 25 indicators grouped in five aggregated scores (Memory, Attention, Language, Executive Function and Visual-Spatial). A global cognitive profile score (P) is calculated with the average of the 5 composed scores. Each time a game is played, results are computed to adjust the user's cognitive profile.
- When a new user registers, he/she is encouraged to play a large set of games covering all cognitive functions. This first phase serves to build the initial cognitive profile (Pinit). On average, each game is done twice, in order to get a reliable marker. It takes about 2 weeks to complete the initial profile.

A previous study made on 85 subjects has shown that intensive training (500 games played) lead to an average improvement of 15.6% based on the original cognitive profile (Croisile et al., 2008). However, there was a high variability of intensity (number of games played per week), which lead to designing a new study to determine the conditions for maximizing effects of computerized training.

Selection process:

• All users were chosen among French, American and German members according to the following criteria:

- Recent members (to ensure no variation in the training program during the study as new games are regularly added)
- Adults over 20 years of age
- Homogeneous training:
    - At least 5% of exercises played from each cognitive domain
    - No more than 50% of exercises played in anyone domain
- Regular and significant training:
    - At least 180 games played during the first 90 days of training, but less than 2500
    - At least 12 training session performed (average of 1 session per week)

• Subjects with "initial" profile outside 2 standard deviations were removed from the population.

Data measured:

- Initial profile (Memory, Attention, Language, Executive Functions, Visuo-Spatial and global Profile): M_{init}, A_{init}, L_{init}, EF_{init}, VS_{init} and P_{init})

- Cognitive profile (Memory, Attention, Language, Executive Functions, Visuo-Spatial and global Profile) after 90 days of training (M_{fin}, A_{fin}, L_{fin}, EF_{fin}, VS_{fin} and P_{fin})
- Number of games played
- Number of training sessions

Computed data:

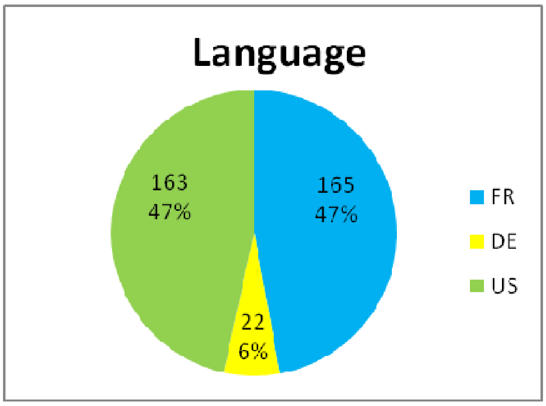
- Cognitive profile progression (Prog) : P_{fin}- P_{init}
- Average games played per session

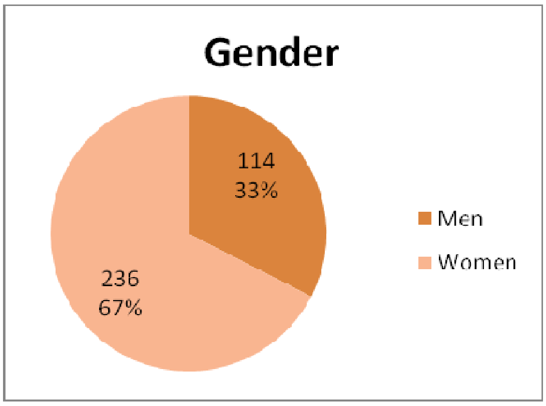
Population

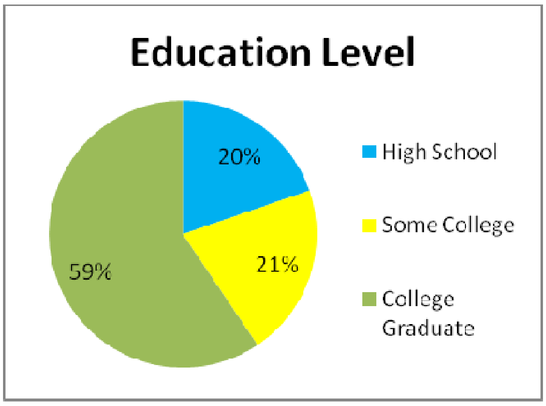
350 subjects met all the criteria.

Table 1: Descriptive statistics of subjects

Variable	Minimum	Maximum	Mean	Standard Deviation
Education Level	1.000	3.000	2.399	0.797
Gender (1=Man ; 2=Woman)	1.000	2.000	1.675	0.469
Age	21.600	86.800	53.840	13.661
# games played	180.000	2374.000	571.353	430.470
#sessions	16.000	137.000	65.160	27.013
Pinit	20.300	66.600	44.388	7.925
Pfin	24.900	77.900	49.613	8.264
Prog (Pfin-Pinit)	-11.900	33.900	5.225	5.969







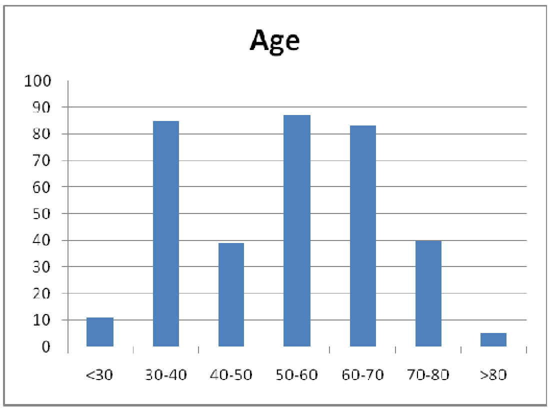


Figure 1: Distribution of population according to language, gender, education level and age.

HAPPYneuron members are predominately women (67%), and skew towards being highly educated (59% college). Interestingly, there is a significant proportion of 30-40 adults, although a good majority are 50 years old or older

Almost half of the population studied was French speaking and the other half English speaking (only 6% of spoke German).

The average initial profile score was 44.388, which is clearly under 50 and therefore below the typical level of their peer group. This shows that average users have some initial cognitive difficulties, which is in line with past analysis of HAPPYneuron members (Croisile et al. 2008).

By construction, the HAPPYneuron profile is normalized according to peer results (the median value 50/100). As a consequence, we should not see significant differences in the results between males and females, the educated and less educated, and the young and elderly.

We have verified with ANOVA that the initial profile does not depend on gender ($F=2.7$ with $p=0.6$), level of education ($F=1.9$ with $p=0.14$), or language ($F=0.8$ with $p=0.43$). There is a very small correlation at a significant level between the initial profile and age (Pearson correlation = -0.142 with $p=0.008$). The assumption is that elderly HAPPYneuron members have more cognitive impairments than young populations.

Each user spanned 65 training sessions in 90 days. As a consequence, the average number of sessions per week was almost 5.

The average number of games played by each user is 571, which is about 6 games per day or 8.8 games per sessions. The very big standard deviation suggests important variations of training intensity.

Effects of training

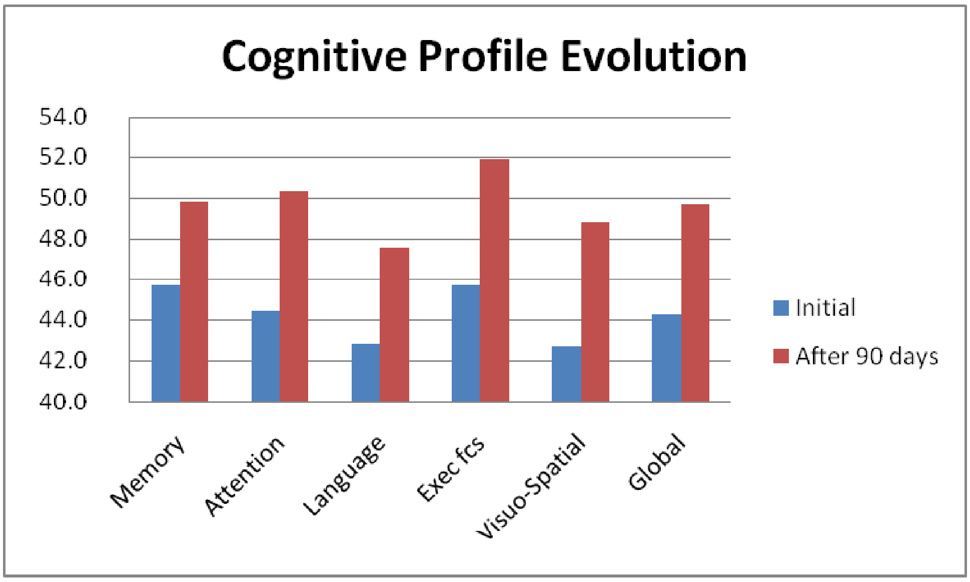


Figure 2: Average cognitive profile before and after training.

Anova analysis between initial and final profiles shows a significant difference ($F=395.4$ with $p<0.0001$). Table 2 shows global and sectorial evolution between initial and final profiles. Cohen size effect between Pinit and Pfin is 0.65 (0.74 if we consider only subjects who played more than 270 games).

Table 2: Average cognitive profile evolution

Mean +/- σ	Memory	Attention	Language	Exe func.	Visuo-spatial	Global
Initial	45.8 +/-9.2	44.5 +/-8.8	43.0 +/-11.0	45.8 +/-9.3	42.8 +/-9.6	44.4 +/-7.9
After 90 days	49.8 +/-8.5	50.2 +/-9.0	47.5 +/-10.5	51.8 +/-8.6	48.7 +/-9.4	49.6 +/-8.3
Evolution	4 +/-7.1	5.7 +/-6.8	4.5 +/-9.4	6.1 +/-7.4	5.9 +/-7.7	5.2 +/-6.0

The high standard deviation of evolution suggests that some factors play important roles on the efficacy of the training activity.

We have verified with ANOVA that evolution does not correlate significantly with gender (F=0.3 with p=0.57), level of education (F=0.9 with p=0.42), language (F=0.3 with p=0.77), or age (F=2.7 with p=0.1).

Conversely, evolution does depend significantly on the initial profile (P=38.4 with p<0.0001) and the intensity of the training: # games played (F=93.0 with p<0.0001), # sessions of training (F=32.5 p<0.0001), games per session ratio (F=38.312, p<0.001). This is confirmed by Pearson correlation matrix (see Table 3). The correlation between Prog and Pinit (-0.319) is intuitive as it is easier to improve when you start with a low profile than with a higher one. The small significant correlation between # sessions and Pinit (-0.237) suggests that people with more cognitive difficulties train more regularly. This is confirmed comparing average number of sessions between the 3 classes of subjects (117 subjects each):

- Pinit <=42 have average number of sessions of 72.1 with 629 games played
- 42<Pinit<47.5 have average number of sessions of 64.4 with 549 games played
- Pinit>47.5 have average number of sessions of 59.0 with 535 games played

Table 3: Correlation between Cognitive Profile Progression and other variables

Variables	Prog	Pinit	# sessions	Game ratio	# games
Prog	**1**	**-0.319**	**0.311**	**0.340**	**0.466**
Pinit		**1**	**-0.237**	0.064	-0.128
# sessions			**1**	-0.036	**0.598**
Game ratio				**1**	**0.711**
# games					**1**

Bold values have a p-value<0.0001

Based on these results, we studied variation of cognitive profile progression according to training intensity (# games played). Figure 3 shows distribution of population according to number of games played (5 classes corresponding to <3; 3-5, 5-7; 7-11 and >11 games per day). As the average game duration is 188 seconds, these 5 classes correspond to an average training duration per day of: < 9 min, 9-16 min, 16-22 min, 22-34 min, > 34 min.

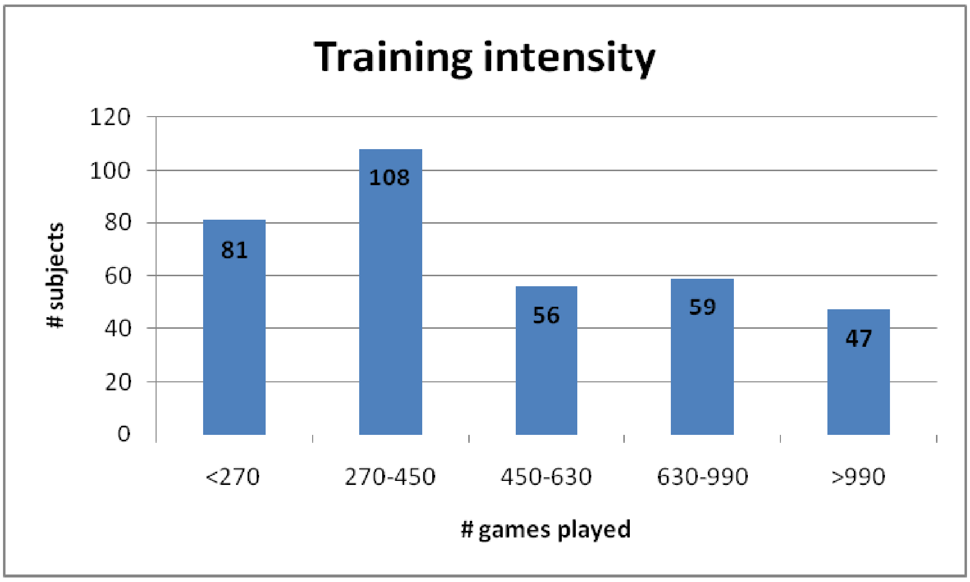


Figure 3: Five classes of subjects according to the total number of games played.

As shown by Table 4, there is a regular increase of profile improvement according to training intensity.

Table 4: Average increase of Cognitive Profile according to training intensity

# games	<270	270-450	450-630	630-990	>990
eq. games per day	<3	3-5	5-7	7-11	>11
eq. time(min) per day	<10	10-16	16-22	22-34	>34
Prog (M+/-σ)	2.39 +/- 4.03	3.81 +/- 6.03	5.13 +/- 4.90	7.33 +/- 5.75	10.83 +/- 5.58
% improvement	5.2%	8.8%	11.1%	16.1%	26.5%

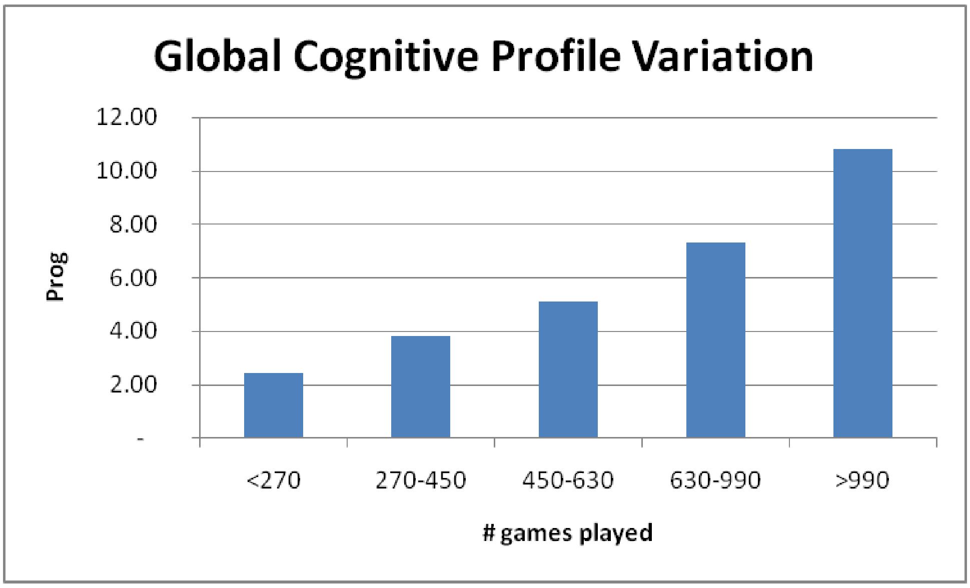


Figure 4: Global cognitive profile improvement according to training intensity.

The next diagram displays each class of training intensity and the number (in %) of people regressing or improving their cognitive profile of less than 5 points, between 5 and 10 points, between 10 and 15 points, and finally improving more than 15 points.

Figure 5 clearly shows that the more people participate in the brain training exercises, the more they improve their cognitive profile. It is further noted that in the group of subjects who train the most (more than 990 games), no one regresses in their cognitive performance.

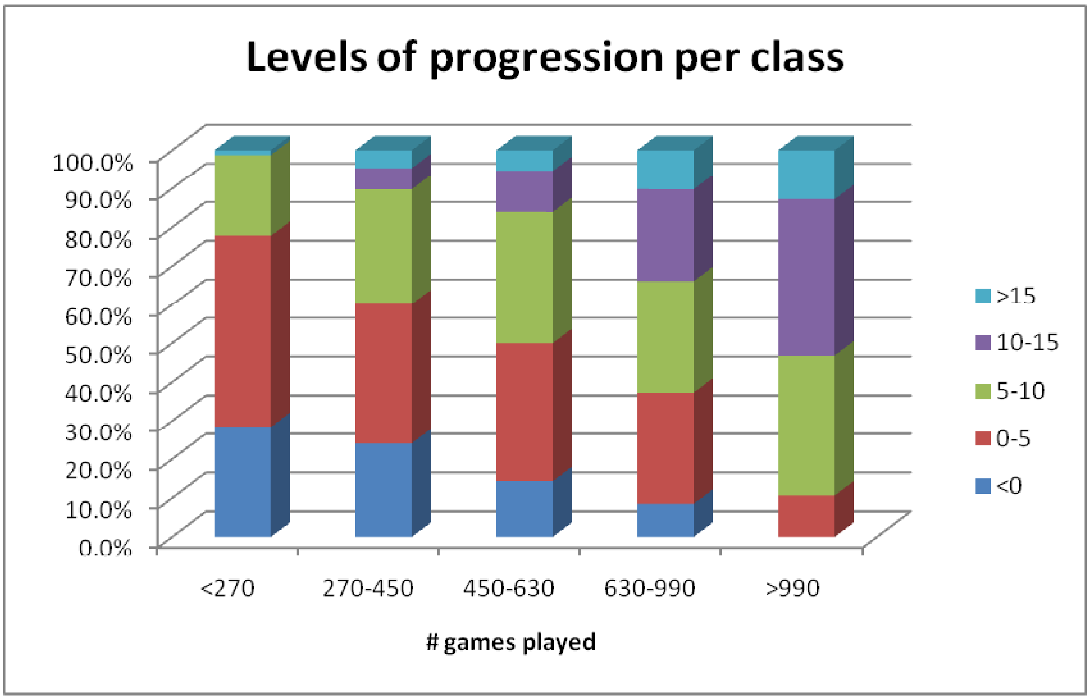


Figure 5: Levels of evolution of cognitive profile (5 classes) according to the number of games played.

We are now equipped to ask the question, can the progression of a cognitive profile be explained only by the development of task expertise or is it really a measure of cognitive improvement? In this study, subjects are anonymous people on the web, we do not have the ability to check with pre and post training neuropsychological assessments to unequivocally validate this point.

The size of the library of games (37) and the average training intensity (571 games) suggest that subjects played each game about 15 times over 90 days, which means that each game is played only once a week on average for intermediate players and about twice a week for the most intensive players. Considering that each game has between 3 and 50 game difficulty levels, the number of times a game is played at a given level is very limited. As a consequence, we consider that the task learning effect is minor compared to global cross function improvement.

Conclusion

Data show a significant improvement of cognitive profile, which is correlated to the intensity of training but not correlated to gender, level of education, language or age. The number of exercises in the library is a critical part of a brain training program to ensure a transversal improvement and not an exercise-dependent improvement, which could be directly linked to task learning. Data analysis suggests a training recommendation of 30-40 minutes sessions, 3 to 5 days a week for maximizing effects of 90 days of brain training.

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