Effects of daily training amount on visual motion perceptual learning

Yongqian Song
School of Psychological and Cognitive Sciences and Beijing Key Laboratory of Behavior and Mental Health, Peking University, Beijing, People's Republic of China
IDG/McGovern Institute for Brain Research, Peking University, Beijing, People's Republic of China
Peking-Tsinghua Center for Life Sciences, Peking University, Beijing, People's Republic of China

Nihong Chen
Department of Psychology, Tsinghua University, Beijing, People's Republic of China
IDG/McGovern Institute for Brain Research, Tsinghua University, Beijing, People's Republic of China

Fang Fang
School of Psychological and Cognitive Sciences and Beijing Key Laboratory of Behavior and Mental Health, Peking University, Beijing, People's Republic of China
IDG/McGovern Institute for Brain Research, Peking University, Beijing, People's Republic of China
Peking-Tsinghua Center for Life Sciences, Peking University, Beijing, People's Republic of China

Perceptual learning has been widely used to study the plasticity of the visual system in adults. Owing to the belief that practice makes perfect, perceptual learning protocols usually require subjects to practice a task thousands of times over days, even weeks. However, we know very little about the relationship between training amount and behavioral improvement. Here, four groups of subjects underwent motion direction discrimination training over 8 days with 40, 120, 360, or 1080 trials per day. Surprisingly, different daily training amounts induced similar improvement across the four groups, and the similarity lasted for at least 2 weeks. Moreover, the group with 40 training trials per day showed more learning transfer from the trained direction to the untrained directions than the group with 1080 training trials per day immediately after training and 2 weeks later. These findings suggest that perceptual learning of motion direction discrimination is not always dependent on the daily training amount and less training leads to more transfer.

Introduction

The human brain can achieve long-term improvement in perceptual sensitivity as a result of learning (Fahle & Poggio, 2002). A prevailing view on this improvement is that "practice makes perfect," implying that tens of thousands of trials of training over days or weeks are necessary to induce substantial improvement in performance (Aberg et al., 2009; Banai & Lavner, 2014; Censor, Sagi, & Cohen, 2012; Chung, Levi, & Li, 2006; Husk, Bennett, & Sekuler, 2007; Sigman & Gilbert, 2000). However, several recent studies showed that a small amount of training was sufficient to induce perceptual learning (Amar-Halpert et al., 2017; Hussain, Sekuler, & Bennett, 2009; Molloy et al., 2012). Hussain et al. (2009) examined the amount of practice needed to improve performance on texture and face identification. In a texture identification task, they found that 105 trials of practice on the first day were required to enhance performance relative to the control group at the start of testing on the second day. In a face identification task, even only 21 trials of practice could enhance performance relative to the control group (Hussain et al., 2009). In a recent study on texture discrimination learning (Amar-Halpert et al., 2017), participants underwent a practice for 252 trials on the first day, and then they returned for 3 daily sessions with only five near-threshold trials per session. Discrimination thresholds were measured on the first day and the fifth day. Intriguingly, such short training resulted in a remarkable learning effect. Based on this finding, Amar-Halpert and colleagues proposed that learning was due to a memory reactivation mechanism.

It has been shown that training beyond a certain amount could not further benefit learning (Karni & Sagi, 1993; Savion-Lemieux, T., & Penhune, V. B., 2005). In a temporal–interval discrimination task, Wright and Sabin (2007) trained subjects for either 360 or 900 trials per day for 6 days. Significant learning occurred with both 360 and 900 training trials per day, and 900 training trials per day did not induce greater improvement relative to 360 training trials. Likewise, similar effects were also observed with a micro-reading letter task (Ofen-Noy, Dudai, & Karni, 2003), a visual texture discrimination task (Karni & Sagi, 1993), and an auditory identification task (Roth, 2005). Notably, overtraining could even be detrimental to the learning effect already acquired (Ashley & Pearson, 2012; Censor, Karni, & Sagi, 2006; Mednick et al., 2002; Mednick, Arman, & Boynton, 2005; Ofen, Moran, & Sagi, 2007). Mednick et al. (2005) measured the performance on a texture discrimination task in three 1-hour sessions and found that the performance deteriorated steadily both within and across the first two sessions. Because repeated within-day testing led to a retinotopically specific decrease in performance, such perceptual deterioration is not simply due to general fatigue or boredom. Therefore, intensive training might lead to limited behavior improvement.

In this study, we aimed to investigate the relationship between daily training amount and behavioral improvement—how does the daily training amount modulate the magnitude and specificity of the perceptual learning effect with a motion direction discrimination task? We were also interested in how long the modulation effects could persist. Participants were trained for 40, 120, 360, or 1080 trials per day with a visual motion direction discrimination task. Threshold measurements were conducted before, one day after, and two weeks after eight training days at the trained direction and the untrained directions (30°, 60°, and 90° away from the trained direction).

Methods

Subjects

Fifty-nine subjects (21 males) participated in the study. Their ages ranged from 18 to 28. All subjects were naïve to the purpose of the study and had never participated in any perceptual learning experiment before. They were right-handed with reported normal or corrected-to-normal vision and had no known neurological or visual disorders. They gave written, informed consent in accordance with the procedures and protocols approved by the human subject review committee of Peking University. This study adhered to the Declaration of Helsinki.

Stimuli and apparatus

Similar to our previous study (Chen et al., 2015), visual stimuli were random-dot kinematograms (RDKs) with 100% coherence (Figure 1A). All dots in a RDK moved in the same direction (luminance: 3.76 cd/m^2; diameter: 0.1°; speed: 10°/sec). At any one moment, 400 dots were visible within an 8° circular aperture. The dots were presented against a gray background (luminance: 19.8 cd/m^2). The visual stimuli were presented on an IIYAMA HM204DT 22-in monitor, with a spatial resolution of 1024 × 768 and a refresh rate of 60 Hz. Subjects viewed the stimuli from a distance of 60 cm. Their head was stabilized using a head and chin rest.

Designs

Fifty-nine subjects were randomly assigned into four training groups (n = 12, 11, 12, and 12), respectively and a control group (n = 12). Four training groups underwent four phases (Figure 1B): pretraining test (Pre), motion direction discrimination training, post-training test 1 (Post1), and post-training test 2 (Post2). The control group only underwent Pre, Post1, and Post2. Pre and Post1 took place on the days immediately before and after training, and Post2 took place 2 weeks after training.

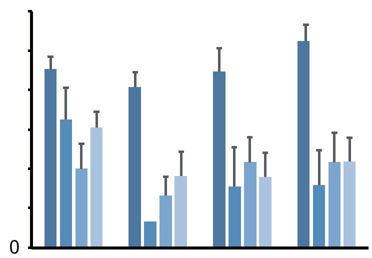
During the training phase, each subject underwent eight daily training sessions to perform a motion direction discrimination task at a direction of θ, which was chosen randomly from eight directions: 22.5°, 67.5°, 112.5°, 157.5°, 202.5°, 247.5°, 292.5°, and 337.5° (0° was the rightward direction) at the beginning and was fixed for all the sessions. For the four training groups, a daily training session consisted of 1, 3, 9, and 27 QUEST (Watson & Pelli, 1983) staircases of 40 trials, corresponding with 40, 120, 360, or 1080 trials, respectively. In a trial, two RDKs with motion directions of $\theta + \Delta\theta/2$ and $\theta - \Delta\theta/2$ were presented successively for 200 ms each and were separated by a 600-ms blank interval. The temporal order of these two RDKs was randomized. Subjects were asked to make a two-alternative forced-choice judgment of the direction of the second RDK relative to the first one (clockwise or counterclockwise). Informative feedback was provided

[redacted]

7 QUEST

[redacted]

A



significant, (3, 43) = 2.383, < 0.1. The main effect of test was not significant, (1, 43) = 1.035, = 0.315, and the inte action between test and t aining amount was not significant eithe , (3, 43) = 0.242, = 0.867. Then, we made compa isons between t aining amount conditions at Post1 and Post2. Planned -tests showed that the g oup eceiving 27 QUEST stai cases t aining pe day exhibited st onge specificity than the g oup eceiving 1 QUEST stai case t aining pe day at Post1, (22) = –2.779, < 0.01, and Post2, (22) = –1.929, < 0.05. Ou esults demonst ated that less t aining led to less specificity o mo e t ansfe , and the cha acte istic lasted fo at least two weeks.

Test–retest e ect

It emains unclea to what extent the pe fo mance imp ovements in the t ained and unt ained di ections a e due to a test- etest effect occu ing at P e, Post1, and Post2. To uantify the test– etest effect, we collected data f om a cont ol g oup, which only unde went P e, Post1, and Post2. Relative to P e, the pe cent imp ovements ave aged ac oss the fou di ections we e 3.095%, one-sample -test (47) = 0.656, = 0.515, at Post1 and 18.116%, (47) = 4.401, < 0.001, at Post2. Notably, the imp ovements at the unt ained di ection at Post2 we e la gely due to the test- etest effect.

Discussion

In this study, we examined the elationship between daily t aining amount and two visual lea ning outcomes: the imp ovement at the t ained featu e, and the t ansfe effect to the unt ained featu es. We found that (1) a small daily t aining amount of 40 t ials was sufficient to induce a significant behavio al imp ovement; no fu the imp ovement was obse ved in g oups with la ge daily t aining amounts and (2) the g oup with the smallest daily t aining amount exhibited the la gest t ansfe effect. These effects pe sisted up to 2 weeks afte t aining. These findings shed light on dete mining the t aining amount in p actical application and help to bette unde stand the ole of t aining amount in some key ideas such as consolidation– eactivation, t ansfe , and stabilization in lea ning.

T aditional pe ceptual lea ning studies have hund eds o even thousands of t aining t ials pe day. He e we show that only 40 t ials of daily p actice we e enough to t igge an imp ovement compa able to 1080 t ials of daily p actice. This finding suppo ts a memo y- eactivation f amewo k fo pe ceptual lea ning. Th oughout multiple t aining sessions, the lea ning effects gained f om individual t aining sessions t ansfo m f om sho t- to long-te m memo y via a p ocess named consolidation (McGaugh, 2000; W ight & Sabin, 2007). Afte the initial memo y consolidation has been established, b ief eactivations may t igge econsolidation-like p ocesses to imp ove the existing pe ceptual memo y (Ama -Halpe t et al., 2017; Bang et al., 2018). Ama -Halpe t et al. (2017) have shown that dec easing the standa d t aining amount (f om 252 t ials to 5 t ials) on day 2 to day 4 led to no change in the ove all lea ning effect. Howeve , fu the dec easing the t aining f om a standa d to a small amount on day 1 led to a significant dec ease in the ove all lea ning effect. In the p esent study, all the subjects unde went a p etest of 400 t ials fo each condition, which established the new memo y. Afte that, 40 t ials of daily t aining we e sufficient to eactivate the memo y fo econsolidation. Ou esults indicate that motion pe ceptual lea ning, as a specific kind of p ocedu al memo y, might function via a consolidation- eactivation mechanism.

In cont ast, ove t aining might be det imental to pe ceptual lea ning, which was efe ed to as pe ceptual dete io ation (Mednick et al., 2002, 2005). Induced by too much t aining, pe ceptual dete io ation is possibly due to senso y adaptation (Censo et al., 2006), st engthening less efficient neu onal connections and accumulating noise in the b ain netwo k (Censo & Sagi, 2008), o changes in the ability fo attention to selectively enhance the esponses of low-level senso y neu ons (Mednick et al., 2005). In ou stude.4(dail)8w me42.4(l

(Lengyel & Fise , 2019). In the p esent study, stimuli va iation was int oduced at the p etest and post-test stages, and was kept constant ac oss the g oups. This test gave subjects a sufficient amount of t aining (400 t ials fo each di ection) ove a elatively b oad featu e space (fou motion di ection with 0°, 30°, 60°, and 90° offset f om the t ained di ection). Du ing 8 t aining days, subjects eceived t aining on a specified motion di ection with a nea -th eshold va iation. Note that we used continuous stai cases fo each t aining day; except fo the fi st stai case, each stai case sta ted with the th eshold de ived f om the p eceding stai case. Ou t aining p otocol esembles the single p olonged stai case used in Hung and Seitz (2014) and othe pe ceptual lea ning studies (Jehee et al., 2012; Schoups et al., 1995). The efo e, by inc easing the t aining amount, we inc eased the numbe of nea -th eshold t ials. Because such t aining ove - ep esents a pa ticula featu e in the space, inc easing the daily t aining amount leads to ove fitting and g eate specificity. Consistent with Hung and Seitz (2014), ou esults showed that p olonged t aining at th eshold affects t ansfe in pe ceptual lea ning. It is wo th mentioning that the account of stimuli va iation and specificity in pe ceptual lea ning is eminiscent of Eleano Gibson and James Gibson's ecological app oach to pe ception, which suggested mo e va iability led to a mo e gene al lea ning esult (Gibson & Gibson, 1955). The 1 QUEST g oup might unde go a la ge va iation, the efo e showing mo e t ansfe than the 27 QUEST g oup.

Pe ceptual lea ning with fine featu e disc imination tasks usually esults in high specificity and less t ansfe (e.g., Liu, 1999; Shiu & Pashle , 1992). Liu (1999) epo ted that, although lea ning in a motion disc imination task with a 3° di ectional diffe ence was st ongly specific to the t aining di ection, lea ning t ansfe ed to new motion di ections with an 8° di ectional diffe ence. The idea that t aining p ecision modulates the deg ee of t ansfe in pe ceptual lea ning has been suggested in ea lie psychophysical studies (Ahissa & Hochstein, 1997; Jete et al., 2009) and is ecently modeled using a deep neu al netwo k (Wenliang & Seitz, 2018).

In addition, ou p esent findings p ovided the fi st piece of evidence fo the long-te m modulation effect of t aining amount on specificity, which pe sisted fo at least 2 weeks afte t aining. Futu e studies a e needed to evaluate how the deg ee of t ansfe was modulated unde diffe ent manipulations of the stimuli va iations, such as changing the ange of stimuli in the featu e space, changing the p obability dist ibution of stimuli (e.g., the atio between the t aining amount of the t ained and unt ained featu es), and changing the time point the va iation is p esented (e.g., ea ly, middle, o late t aining phase).

T aining with a small daily amount p ovides a p omising alte native p otocol fo pe ceptual lea ning studies in the futu e. When deciding on the t aining amount in p actice, the following facto s should be taken into conside ation. (1) Gene alization. Based on the cu ent and p evious lea ning studies with a motion o o ientation disc imination pa adigm, a la ge daily t aining amount leads to less t ansfe to the unt ained featu e o spatial location. If one aims to induce a lea ning effect highly specific to the t ained featu e fo a baseline cont ol, a classical t aining pa adigm with hund eds o thousands of daily t aining t ials would be e ui ed. Othe wise, fewe t ials (e.g., 40 t ials o 5 t ials in the middle phase of lea ning in Ama -Halpe t et al. [2017]) in a daily session may be a choice fo efficiency. (2) Stability. Acco ding to the hype stabilizes account of ove lea ning, the lea ning effect becomes less susceptible to inte fe ence with an inc easing daily t aining amount. The efo e, if subjects leas(1)yis6⊠g⊠TD⊠[n oti

, ,
, ' ,

Acknowledgments

Suppo ted by the National Natu al Science Foundation of China (31930053, 31671168, 31421003, and 31971031), Beijing Municipal Science and Technology Commission (Z181100001518002), and Beijing Academy of A tificial Intelligence (BAAI).

Comme cial elationships: none.
Co esponding autho s: Fang Fang and Nihong Chen.
Email: ffang@pku.edu.cn, nihongch@tsinghua.edu.cn.
Add ess: School of Psychological and Cognitive Sciences, Peking Unive sity, Beijing 100871, People's Republic of China.

References

Abe g, K. C., Ta taglia, E. M., & He zog, M. H. (2009). Pe ceptual lea ning with Chev ons e ui es a minimal numbe of t ials, t ansfe s to unt ained di ections, but does not e ui e sleep. , 4 (16), 2087–2094.

Ahissa , M., & Hochstein, S. (1997). Task difficulty and the specificity of pe ceptual lea ning. , 3 (6631), 401–406.

Ama -Halpe t, R., Lao -Maayany, R., Nemni, S., Rosenblatt, J. D., & Censo , N. (2017). Memo y eactivation imp oves visual pe ception. , 20(10), 1325–1328.

Ashley, S., & Pea son, J. (2012). When mo e e uals less: Ove t aining inhibits pe ceptual lea ning owing to lack of wakeful consolidation. , 2 (1745), 4143–4147.

Banai, K., & Lavne , Y. (2014). The effects of t aining length on the pe ceptual lea ning of time-comp essed speech and its gene alization. , 13 (4), 1908–1917.

Bang, J. W., Shibata, K., F ank, S. M., Walsh, E. G., G eenlee, M. W., Watanabe, T., . . . Sasaki, Y. (2018). Consolidation and econsolidation sha e behaviou al and neu ochemical mechanisms. , 2(7), 507–513.

Censo , N., Ka ni, A., & Sagi, D. (2006). A link between pe ceptual lea ning, adaptation and sleep. , 4 (23), 4071–4074.

Censo , N., & Sagi, D. (2008). Benefits of efficient consolidation: Sho t t aining enables long-te m esistance to pe ceptual adaptation induced by intensive testing. , 4 (7), 970–977.

Censo , N., Sagi, D., & Cohen, L. G. (2012). Common mechanisms of human pe ceptual and moto lea ning. , 13(9), 658–664.

Chen, N., Bi, T., Zhou, T., Li, S., Liu, Z., & Fang, F. (2015). Sha pened co tical tuning and enhanced co tico-co tical communication cont ibute to the long-te m neu al mechanisms of visual motion pe ceptual lea ning. , 115, 17–29.

Chung, S. T. L., Levi, D. M., & Li, R. W. (2006). Lea ning to identify cont ast-defined lette s in pe iphe al vision. , 4 (6–7), 1038–1047.

Fahle, M., & Poggio, T. (Eds.). (2002). L . Camb idge, MA: MIT P ess.

Fox, O., Ka ni, A., & Adi-Japha, E. (2016). The consolidation of a moto skill in young adults with ADHD: Sho te p actice can be bette . , 51 52, 135–144.

F angou, P., Emi , U. E., Ka laftis, V. M., Nettekoven, C., Hinson, E. L., La combe, S., . . . Kou tzi, Z. (2019). Lea ning to optimize pe ceptual decisions th ough supp essive inte actions in the human b ain. , 10(1), 474.

Gibson, J. J., & Gibson, E. J. (1955). Pe ceptual lea ning: Diffe entiation o en ichment? , 2(1), 32–41.

Goldhacke , M., Rosenga th, K., Plank, T., & G eenlee, M. W. (2014). The effect of feedback on pe fo mance and b ain activation du ing pe ceptual lea ning. , , 99–110.

Hung, S.-C., & Seitz, A. R. (2014). P olonged T aining at Th eshold P omotes Robust Retinotopic Specificity in Pe ceptual Lea ning. , 34(25), 8423–8431.

Husk, J. S., Bennett, P. J., & Sekule , A. B. (2007). Inve ting houses and textu es: Investigating the cha acte istics of lea ned inve sion effects. , 4 (27), 3350–3359.

Hussain, Z., Sekule , A. B., & Bennett, P. J. (2009). How much p actice is needed to p oduce pe ceptual lea ning? , 4 (21), 2624–2634.

Hussain, Z., Bennett, P. J., & Sekule , A. B. (2012). Ve satile pe ceptual lea ning of textu es afte va iable exposu es. , 1, 89–94.

Jehee, J. F. M., Ling, S., Swishe , J. D., van Be gen, R. S., & Tong, F. (2012). Pe ceptual lea ning selectively efines o ientation ep esentations in ea ly visual co tex. , 32 (47), 16747–16753.

Jete , P. E., Doshe , B. A., Pet ov, A., & Lu, Z. L. (2009). Task p ecision at t ansfe dete mines specificity of pe ceptual lea ning. [illegible] , (3), 1–1.

Jete , Pamela E., Doshe , B. A., Liu, S.-H., & Lu, Z.-L. (2010). Specificity of pe ceptual lea ning inc eases with inc eased t aining. , *50*(19), 1928–1940.

Ka ni, A., & Sagi, D. (1993). The time cou se of lea ning a visual skill. , *3 5*(6443), 250–252.

Lengyel, G., & Fise , J. (2019). The elationship between initial th eshold, lea ning, and gene alization in pe ceptual lea ning. [illegible] , *1* (4), 28.

Liu, Z. (1999). Pe ceptual lea ning in motion disc imination that gene alizes ac oss motion di ections. , (24), 14085–14087.

Liu, L., Kuyk, T., & Fuh , P. (2007). Visual sea ch t aining in subjects with seve e to p ofound low vision. , *4* , 2627–2636.

McGaugh, J. L. (2000). Memo y—A centu y of consolidation. , *2* (5451), 248–251.

Mednick, S. C., A man, A. C., & Boynton, G. M. (2005). The time cou se and specificity of pe ceptual dete io ation. , *102*(10), 3881–3885.

Mednick, Sa a C., Nakayama, K., Cante o, J. L., Atienza, M., Levin, A. A., Pathak, N., . . . Stickgold, R. (2002). The esto ative effect of naps on pe ceptual dete io ation. , *5*(7), 677–681.

Molloy, K., Moo e, D. R., Sohoglu, E., & Amitay, S. (2012). Less is mo e: Latent lea ning is maximized by sho te t aining sessions in audito y pe ceptual lea ning. *[illegible]* , (5), e36929.

Ofen, N., Mo an, A., & Sagi, D. (2007). Effects of t ial epetition in textu e disc imination. , *4* (8), 1094–1102.

Ofen-Noy, N., Dudai, Y., & Ka ni, A. (2003). Skill lea ning in mi o eading: How epetition dete mines ac uisition. , *1* (2), 507–521.

Polat, U. (2009). Making pe ceptual lea ning p actical to imp ove visual functions. , *4* (21), 2566–2573.

Robe tson, E. M. (2018). Memo y instability as a gateway to gene alization. *[illegible]* , *1* (3), e2004633.

Roth, D. A.-E. (2005). A latent consolidation phase in audito y identification lea ning: Time in the awake state is sufficient. *[illegible]* & [illegible] , *12*(2), 159–164.

Savion-Lemieux, T., & Penhune, V. B. (2005). The effects of p actice and delay on moto skill lea ning and etention. , *1 1*(4), 423–431.

Schoups, A. A., Vogels, R., & O ban, G. A. (1995). Human pe ceptual lea ning in identifying the obli ue o ientation: Retinotopy, o ientation specificity and monocula ity. [illegible] , *4 3*(3), 797–810.

Shibata, K., Sasaki, Y., Bang, J. W., Walsh, E. G., Machizawa, M. G., & Tamaki, M., . . . Watanabe, T. (2017). Ove lea ning hype stabilizes a skill by apidly making neu ochemical p ocessing inhibito y-dominant. , *20*(3), 470–475.

Shiu, L.-P., & Pashle , H. (1992). Imp ovement in line o ientation disc imination is etinally local but dependent on cognitive set. & , *52*